Final Report    $CR-17893$

# Multifunction Display System

## Volume I

February 1973

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Final Report

# MULTIFUNCTION DISPLAY SYSTEM

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# FOREWORD

This report was prepared by the Advanced Technology Laboratories (Burlington, Massachusetts) of the Government and Commercial Systems Division of RCA, under Contract No. NAS-9-12008 entitled "Multiprocessor Computer System Man/Machine Communication Interface Terminal". The effort was sponsored by the Spacecraft Data Management Branch at NASA's Manned Space Center, Houston, Texas and was conducted under the supervision of Messrs. K. Warnick and J. Weldon.

The work was carried out under the overall direction of Mr. F. E. Shashoua, Manager and technical direction of Mr. G. T. Burton, Leader. Major contributions were made to this program by Messrs. B. R. Clay, D. A. Gore, L. A. Perretta, P. J. Nesbeda, R. Tetrev and B. W. Siryj. Mr. Clay was responsible for the development of the holographic recording and projection systems. He was assisted by Mr. Gore. Mr. Gore was also responsible for the recording of the index holograms. Mr. Perretta was responsible for coating, plating and embossing of the holographic material. Mr. Nesbeda designed and implemented the controller subsystem. Mr. Siryj designed the transport mechanism. Control electronics for the transport system were developed by Mr. Tetrev.

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# ABSTRACT

The report describes effort conducted under Contract No. NAS-9-12008 to design, construct and deliver a Multifunction Display Man/Machine Interface for use with a $(4\pi)$ IBM-360 System. The delivered system is capable of displaying super-imposed volatile alphanumeric and graphical data on a 512 x 512 element plasma panel, and holographically stored multicolor archival information. The volatile data may be entered from a keyboard or by means of an I/O interface to the 360 system. A two-page memory local to the display is provided for storing the entered data. The archival data is stored as a phase hologram on a vinyl tape strip. This data is accessible by means of a rapid transport system which responds to inputs provided by the I/O channel on the keyboard. As many as 500 frames may be stored on a tape strip for access in under 6 seconds.

This report contains the system operating procedures, a complete system description and a discussion of the holographic recording and display techniques employed. The rationale leading to the selection of holography as the archival storage technique is also presented.

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# Section I

# INTRODUCTION

This report describes the operating characteristics of and techniques employed in a Multifunction Display System delivered to NASA-MSC under Contract NAS-9-12008. The system, shown in Fig. 1-1, is designed to present archival multicolor and volatile alphanumeric information for superimposed and registered viewing. System operation is controlled by a remote computer and by a local keyboard.

The archival information is holographically stored on a vinyl tape strip. The stored information may consist of continuous tone black and white or color information which when displayed is presented over an 8-1/2-inch x 8-1/2-inch viewing aperture. The delivered system is capable of storing and rapidly accessing 500 holographic frames.

The volatile alphanumeric and graphical information is presented on an 8-1/2-inch x 8-1/2-inch, 512 x 512 element plasma panel of the type constructed by Owens-Illinois. This panel is positioned in the image plane of the holographic system; it is a binary device presenting the information by activating a neon discharge in addressed elements of the panel. The plasma panel is transparent allowing rear projection of the holographically stored information through the panel for simultaneous viewing of the composite information.

The Multifunction Display System contains computer interface, logic control, keyboard entry, alphanumeric character and vector generation, holographic storage and projection, rapid retrieval transport, and a plasma panel and plasma panel drive electronics subsystems. These systems, as well as operating and maintenance procedures are described in the following sections of this report. The rationale leading to the selection of holography as the archival storage technique is presented in Section IV.
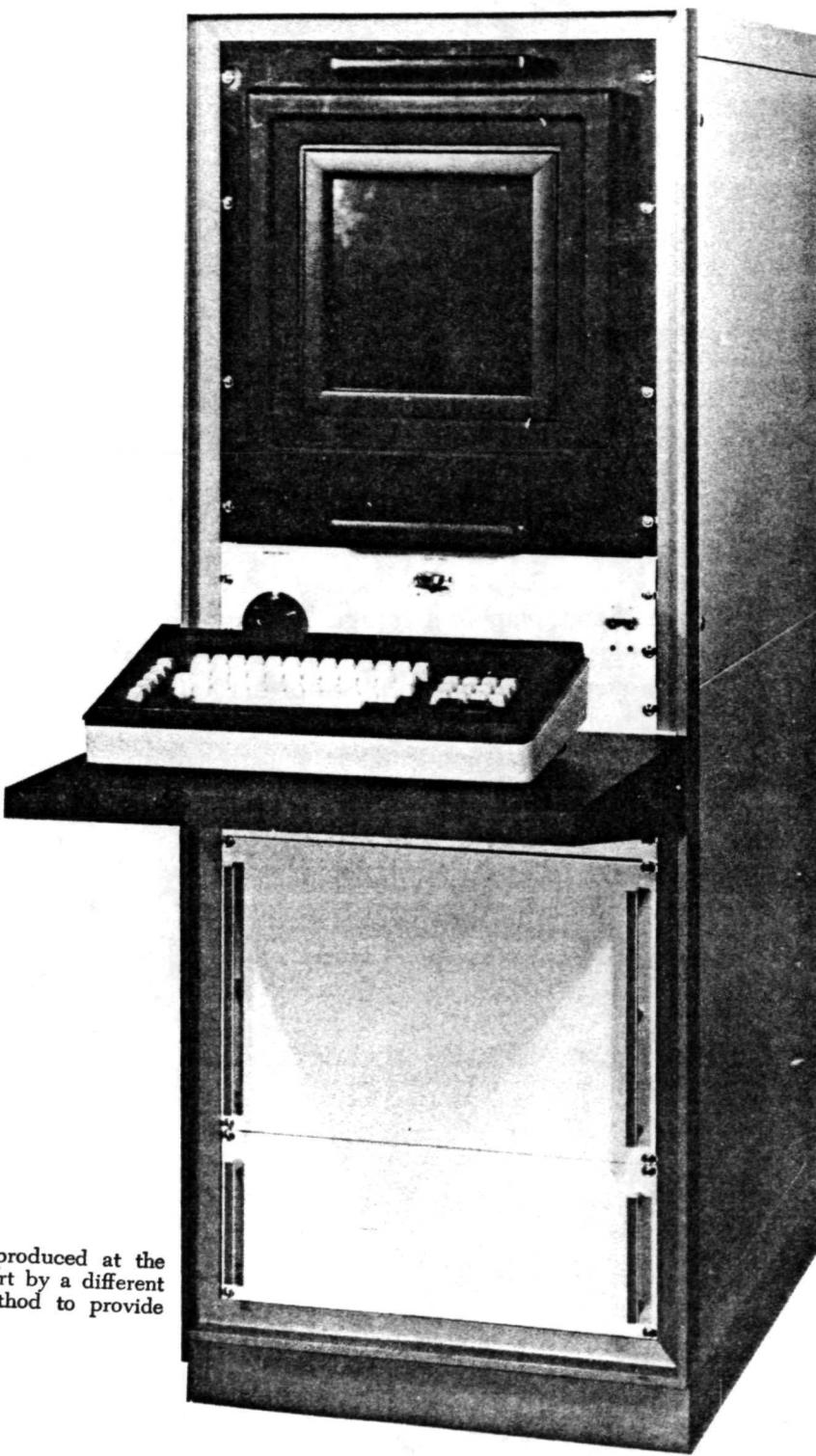
Fig. 1-1. Multifunction Display, front view.

# OPERATING PROCEDURES

## A. CONTROLS

The Multifunction Display System is a keyboard controlled device. There are only three controls available to the operator in addition to those associated with the keyboard. These are a power on-off switch, a holographic display brightness control and a holographic focus control. (See Fig. 2-1.)

### 1. Power ON/OFF

The power on/off switch is located to the right in back of the keyboard. The switch closes a 15-A circuit breaker (115-V, 60-Hz, 1-∅ line) which supplies power to all subsystem components. There are no other on-off switches in the system or auxiliary switching sequences which must be manually performed by the operator. Automatic power-up cycles are initiated in both the local computer controller and the plasma panel system when the on/off switch is closed. The power-up cycle for the plasma panel may not be properly initiated if repeated rapid cycling of the on/off switch is attempted. Thirty seconds should be allowed before turning the system on again. Failure to allow this time delay may result in faulty operation of the plasma panel. Spurious writing in selected areas of the plasma panel may occur. This condition can be eliminated by turning the system off, waiting 30 seconds and turning the unit on again. The condition should not be allowed to persist, although it will in no way harm the equipment; it is a faulty operating mode.

### 2. Hologram Brightness

The holographic display brightness is controlled by means of a variable transformer used to control the holographic projection source brightness. This transformer is located to the left and to the rear of the keyboard. Rotation of the transformer in the clockwise direction increases the display brightness. (A vein switch in the source housing is activated by the blower used to cool the lamp source housing; it is inserted in series with this transformer to prevent turning on the project source without cooling air.) The air intake port on top of the unit must be kept clear.
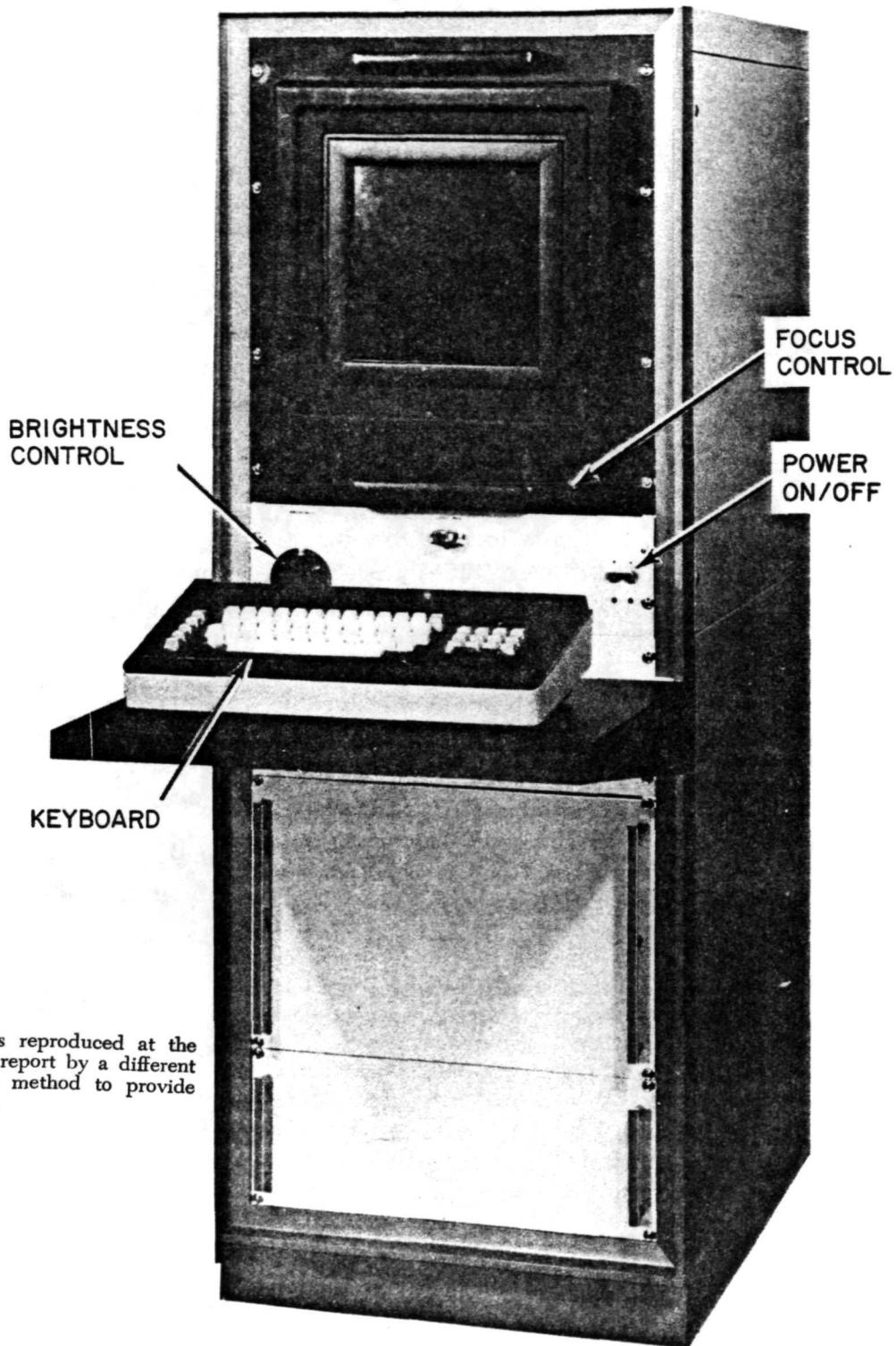
FOCUS
CONTROL

POWER
ON/OFF

BRIGHTNESS
CONTROL

KEYBOARD

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better detail.

Fig. 2-1.  Control location.

3. Focus Control

The focus control for the holographic projection system is a knurled knob located near the lower right hand corner of the viewing screen. This knob is mechanically coupled to the threaded mount of the projection lens. Turning the focus control causes the lens to be moved along the optical axis as it is rotated on its threaded mount to produce a focusing action.

4. Keyboard

The keyboard is divided into three sections as shown in Fig. 2-2. The main body consists of keys arranged in the standard alphanumeric configuration. Keyboard generated codes (ASCI II) are routed directly to the computer. A special function key (⬚) is included as a blue key in this section of the keyboard. This key is used to initiate command functions. Table 2-1 indicates functions that are performed using the function key.

Cursor control keys are located to the left of the main portion of the keyboard. In the alphanumeric mode these keys move the cursor through the character field one character block at a time in the direction indicated on the key face.

The group of keys to the right of the keyboard are function keys. The top two rows of this group are used to control a series of editing functions when the system is operated in the alphanumeric mode. The bottom rows of blue keys allow control of the motion of the holographic tape transport in the up-down and left-right directions. These keys are used to slowly move the tape for the purposes of centering the film in the viewing area. Two red keys are provided at the bottom of this grouping which allow manual rapid search of the holographic tape in the forward and reverse directions.

In addition to the operating controls listed above, removal of the two panels below the keyboard desk reveal the operating controls of the Nova control system and computer interface. During normal operation these switches are not used. Troubleshooting and reprogramming procedures which require the use of these functions should only be attempted after gaining an understanding of the Nova system and Section IIIB.

B. TAPE THREADING

The holographic information is stored as 12-mm x 12-mm holograms on a 16-mm vinyl tape strip. The Multifunction Display System is capable of accommodating up to 500 holographic frames, or approximately 250 inches of tape on a single tape strip.
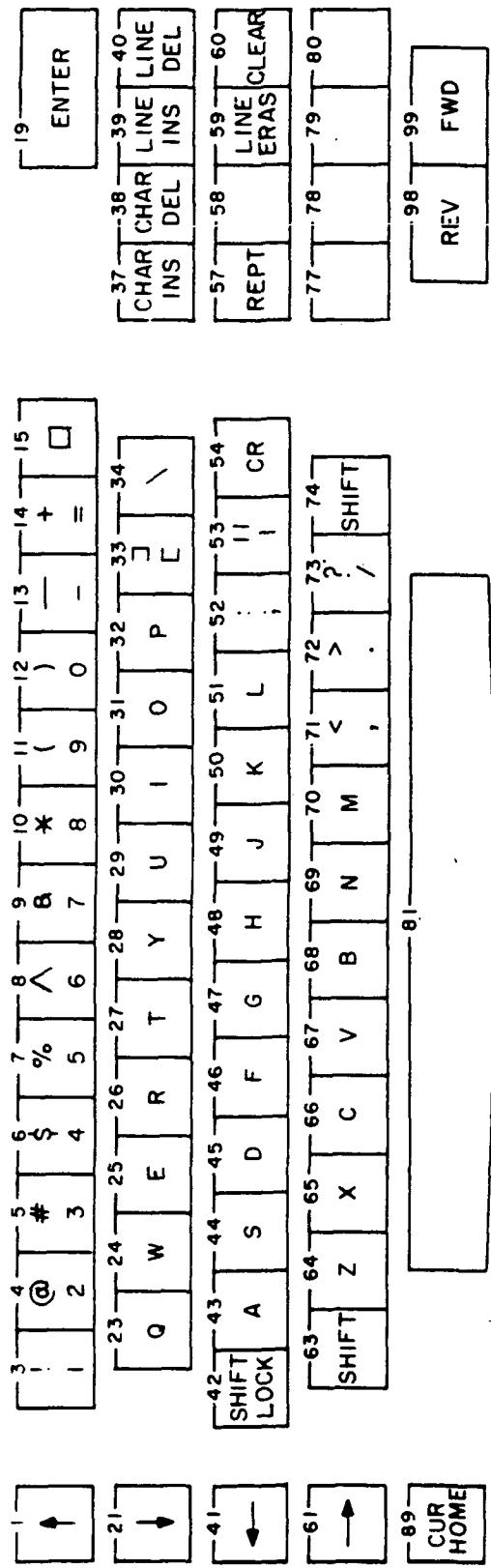
Fig. 2-2. Keyboard.

TABLE 2-1. KEYBOARD FUNCTIONS

---

Function Keys

ENTER                              CHARACTER DELETE
CLEAR                              LINE INSERT
LINE ERASE                         LINE DELETE
CURSOR POSITIONING (4 KEYS)        REPEAT
CURSOR HOME                        SQUARE
CURSOR RETURN
CHARACTER INSERT


Holographic Retrieval

FAST FORWARD                       UP
FAST REVERSE                       DOWN
SLOW FORWARD
SLOW REVERSE


SQUARE FUNCTIONS (Used with square function key)

□DAn□        Displays Alphanumeric page n; n = 1, 2
□DGn□        Displays Graphical page n; n = 1, 2
□DMn□        Display Mixed Alphanumeric and Graphical data
             n = 1, 2
□H nnnn□     Display holographic frame  nnnn
□HRES□       Display computer selected page
□ALPHA□      Set alphanumeric mode
□GRAPH□      Set graphical mode

---

The tape is stored when not in use on a 16-mm reel. When mounted for use in the display system, two light-weight magnesium reels are used. The reels are designed to accommodate 250-inch, 5-mil-thick holographic tapes. The tape reels are partially loaded with tape to allow proper system operation with the thinner tapes (2.0 mils) supplied with the unit. This buildup tape should not be removed when the 2-mil tape supplied with the unit is run.

The tape as it is supplied is wound as if it were on the supply reel so that it can be rewound on the takeup reel for loading. The top of the tape is marked; the edge designated as the top should be wound on the spool so that it is opposite the side of the spool with the embedded gear. The tape is wound on the takeup spool by looking down on the top of the spool (side opposite the embedded gear) and rotating the spool in the

counterclockwise direction. The tape is most conveniently attached to the spool by means of a thin 0.003-inch mylar tape. Care should be taken during this process to insure that the tape is seated squarely on the spool.

The tape is wound on the takeup reel leaving a leader of about 8 inches for threading. This is threaded as shown in Fig. 2-3. Access to the transport is obtained through the rear of the unit. The takeup reel is placed on the spindle located toward the front of the machine. After threading the tape, both takeup arms are adjusted to about 1/2 inch from the most rearward position (toward light source) and the holographic tape is attached to the takeup reel using mylar tape as before.

The tape should be cycled backward and forward using the red advance button on the keyboard through its complete length several times to properly seat the tape on the two reels. After the tape has been seated, automatic retrieval may be accomplished from the keyboard.

Limit switches activated by travel of the takeup arms are provided to inhibit tape motion if the tape breaks or if the takeup arms are not properly adjusted.

If marking as to the tape orientation is not apparent, the proper mounting of the tape can be determined by noting the hologram orientation. The focused image holograms are discernible on the tape strip as embossed maps. These images should be upside-down and on the side of the tape toward the imaging lens.
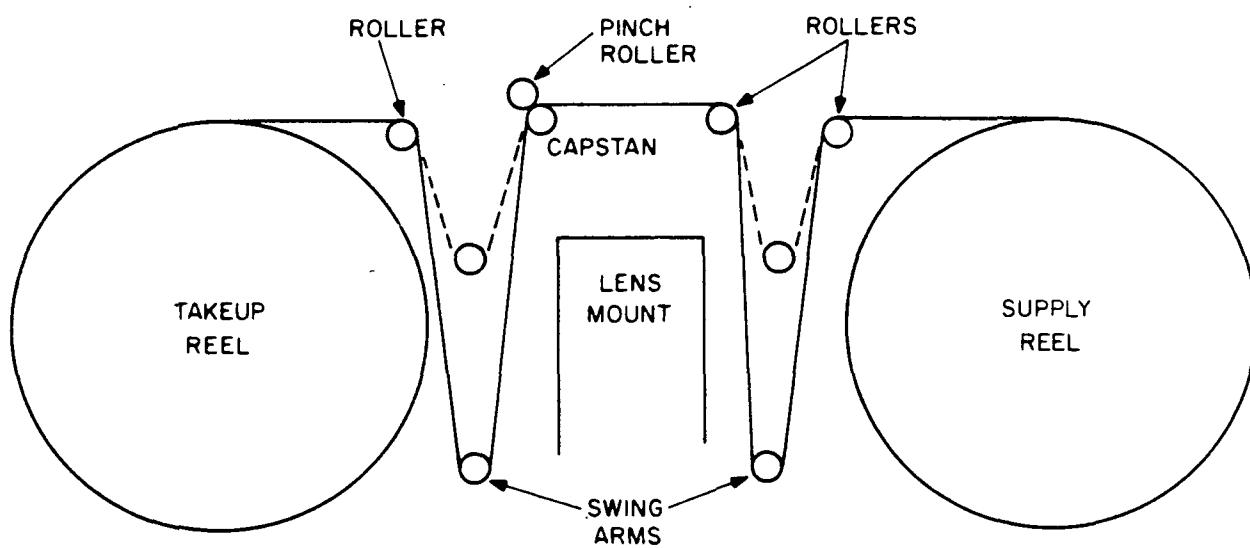


Fig. 2-3. Tape threading.

## C. CLEANING OPTICAL SURFACES

Dust on the optical surfaces and films from contaminants in the air from other parts of the system that slowly develop on the surfaces of the mirrors and lenses would tend to decrease the contrast and brightness of the display. For this reason it may become necessary to clean one or several of the surfaces. Begin by preparing a clean, dust free work area covered with a soft cloth or pad to avoid possible damage if the mirror or lens should be accidently dropped. Secondly, wash your hands thoroughly with a strong liquid detergent. This step is very important since normal body oil and contaminants on your fingers can be transferred to the optical surfaces during the cleaning process. Thirdly, remove the element to be cleaned and blow off any dust or lint on its surface. This step is also extremely important since any dust or lint left on the surface can result in a scratch that will damage it and require replacement. Following this, place several drops of spectroscopic grade acetone on the surface and allow it to freely flow. Then take a piece of lens tissue held by a pair of tweezers and place it on the wetted surface and draw it across the surface to remove any contaminants which have dissolved or floated to the cleaning site. Some contaminants, in particular fingerprints, are not completely soluble in acetone. If this occurs, chlorothen should be used before the acetone to dissolve these difficult-to-remove contaminants. Following cleaning of the surface, replace it in the unit.

# Section III

# SYSTEM DESCRIPTION

## A. FUNCTIONAL DESCRIPTION

Figure 3-1 is a block diagram of the Multifunction Display System (MFDS). The system operation is controlled by a modified Nova 1200 computer. All command and control functions are routed by the Nova controller. Display information may be entered into the MFDS either by the action of an operator through a keyboard or by means of a larger computer system operating over an I/O channel which is equivalent to the IBM/360 multiplex channel. (The input function of this channel is described in Section IIIB.) Control from either the keyboard or the computer port may be used to select and display a particular holographic frame and to introduce alphanumeric and graphical information on the plasma panel.

The holographically stored information is recorded on a 16-mm vinyl tape strip. It is stored using three focused image holograms with different grating orientations
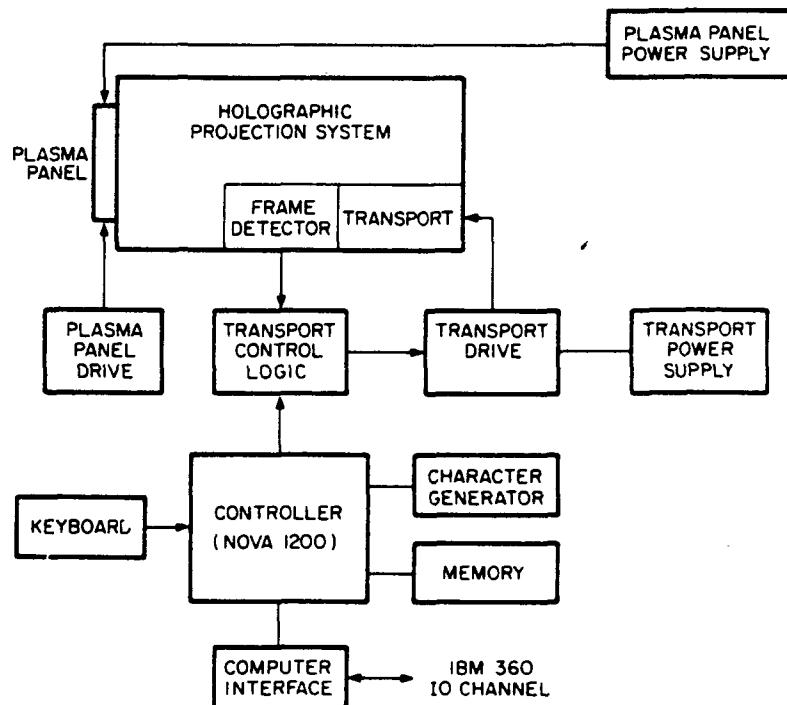


Fig. 3-1. System block diagram.

for the storage of each of the three-element (red, blue and green) separation set; white information is stored using a fourth holographic grating orientation. The focused image recording process used for the storage of the multicolor image information is described in Section IVB.

Indexing information is recorded over the image information using a Fraunhofer hologram in order to allow rapid retrieval of a given holographic frame from as many as 500 holograms stored on a tape strip. The index hologram recording system is described in Section IVC. Access to a given frame is achieved in response to commands generated by the Nova controller. The retrieval process is achieved by the action of the transport system, and a closed loop control system which uses the Fraunhofer indexing information to indicate the film position as it passes through the viewing aperture. A request to retrieve a particular holographic frame may be initiated from the keyboard (by typing ⊡HXXX⊡, where XXX represents the number of the desired frame) or by the remote computer. The logical control of this retrieval function is described in Section IIIE.

The display of volatile information on the plasma panel is also controlled by the Nova. Information generated at the keyboard or by an external computer is transferred to the Nova CPU where it is translated to address, write and erase signals which are acceptable to the plasma panel drive electronics. If alphanumeric information is to be presented, an ASCI II code generated by the keyboard (on the external computer) is routed to a character generator. The output from the character generator is fed to decoding logic associated with the plasma panel placing the information in a position previously specified by the positioning of a cursor (or by an address received over the I/O channel).

As the character is entered on the plasma panel, the character code is also entered in a local memory at a location corresponding to the position at which the information is entered on the page. A two-page memory is provided for storing the alphanumeric information. Either page may be retrieved from memory by the remote computer or from the keyboard (type ⊡DAP⊡ , where P = 1 or 2 and corresponds to the desired page number). Initiation of a page write command causes the information presently displayed to be erased from the panel, the coded information stored for the desired page to be extracted from the specified page memory, and the new information inserted on the panel. The information is fed to the character generation and from there to the plasma panel decoding and drive circuitry. In the delivered system when operated in the alphanumeric mode, 16 Y lines of 10-element x 16-element character block are driven in parallel. The character generator is designed for the parallel drive system.

The Nova system is programmed to allow all (LINE INSERT, LINE DELETE, CHARACTER INSERT, CHARACTER DELETE, etc. ) of the standard editing functions. Provision is also made for positioning of the cursor from the keyboard.

Graphical information may be entered from the computer or from the keyboard. Data entry from the computer through the Nova/IBM-360 interface is described in detail in Section IIIB. Graphical data entry from the keyboard is accomplished in a short vector mode of operation. The system is placed in the graphical mode (type ⌑GRAPH ⌑) causing the generation of a cross-hair cursor which may be positioned to indicate the start location of a vector. The S key is depressed, the cursor is then moved to the desired end position of the vector using the cursor control key for a single cell motion or the U, D, R, L keys on the keyboard for an 8-element motion in the up, down, right and left positions, respectively. When the cursor has been moved to the desired end position, the E key is depressed, a line is then drawn between the two indicated positions. After examination of the vector position, the vector may be inserted in memory by pressing the insert function key. The cross-hair cursor may then be moved to a new position to locate the start of a new vector and the process repeated.

There are two graphical memory pages. Information placed on the plasma panel when an insert command is generated is stored on the page being viewed during the insertion process. Start and stop vector locations are stored in local memory as they are inserted. The page write command ( ⌑DGP⌑, where P represents the number of the desired page) quickly transfers the desired information to the viewing screen. Mixed alphanumeric and graphical information may be displayed by typing ⌑DMP⌑.

In addition to the functions described above, a light pen capability is also anticipated which can be used in conjunction with a blinking asterisk system for identification of items in listings. An auxiliary 16-position memory is provided which allows the system under computer control to place 16 asterisks at any of the character block locations on the display. This memory is then rippled so that each of the 16 asterisks is written and erased in sequence. (The complete memory need not be filled.) The write-erase-write function is detected by a phototransistor pickup. When the light pen is placed over one of the asterisks, a pulse is generated; the time relationship of this pulse to the write-erase-write cycle is monitored and used to gate a code indicating which location is being designated. The code is stored in memory and may be interrogated by the remote computer.

## B. CONTROLLER SUBSYSTEM

This section describes the locate control subsystem of the MFDS. This subsystem consists of a Nova 1200 computer constructed by Data General, a 4025 Data General-IBM Interface, and special purpose function generation and interface electronics.

Table 3-1 lists applicable documents and technical references which are related to this system. A complete software package was delivered with the MFDS. Included in this package are:

TABLE 3-1.  CONTROL SYSTEM REFERENCES

| | |
|---|---|
| (a) | IBM System/360 I/O Interface<br>(Channel to Control Unit)<br>OEMI Form #A22-6843-3 |
| (b) | IBM System/360 Principles of Operation<br>Form A22-6821-7 |
| (c) | Specification for a 512-60 Parallel Addressed Digivue<br>Display/Memory Unit  7/20/71 |
| (d) | How to use the Nova Computers<br>DG NM-5   4/71 |
| (e) | Technical Reference<br><br>4025 IBM System 360/370 Interface<br>DGC 014-000001-01 |
| (f) | 4025 Handler<br><br>DGC 093-000073-01 |
| (g) | 4025 Installation Manual<br><br>DGC 010-000016-00 |

(a)  Detailed flow charts

(b)  Data General's Standard Software Package for the Nova 1200 System

(c)  Source tapes (paper)

(d)  Program binary tapes (paper)

In addition to the software package supplied above, schematics are provided in Appendix I for special circuitry add-in data 16 and 17 of Nova subassembly installation.  Appendix II contains cabling and backplane wiring listings.  Appendices I and II are contained in Volume II.

The following paragraphs of this section describe the subsystem operating procedures.

1.   Keyboard Operation

The keyboard may be used to control information presented on the plasma panel and information presented by means of the holographic projection system.  Table 3-2 indicates the information storage capabilities of the plama panel.  Table 3-3 indicates the page memory storage capacity of the system.

TABLE 3-2.   PLASMA DISPLAY PANEL CHARACTERISTICS AND CONTROL

Display Area: Alphanumeric mode: 32 lines x 51 characters.
Characters are 7 x 9 dot matrix aligned in 10 x 16 character block.
Cursor is a 7-dot line in the 11th position of the character block.

Vector mode: 512-element x 512-element dot matrix.

| Page Memory: | 2 alphanumeric pages | 1632 characters each |
|---|---|---|
| | 2 vector pages | 256 vectors each |
| | 2 projector buffers | 2 frames each |
| | 1 light pen buffer | 20 selection points |

Channel Address:     HEX '070'

TABLE 3-3.   SYSTEM STORAGE CAPABILITIES

| | P1 | P2 | P3 |
|---|---|---|---|
| **ALPHANUMERIC** | | | |
| Write | 1632 bytes/char | 1632 bytes/char | 40 bytes/20 char location |
| Read | 1632 bytes/char | 1632 bytes/char | 2 bytes/2 char location |
| **VECTOR** | | | |
| Write | 1536 bytes/256 vectors | 1536/256 vectors | – |
| Read | 1536 bytes/256 vectors | 1536/256 vectors | – |
| **PROJECTOR** | | | |
| Write | 2 bytes/1 frame | 2/1 frame | – |
| Read | 4 bytes/2 frame | 4/2 frame | – |
| **POINTS** | | | |
| No data buffering defined | | | |

Operation from the keyboard is controlled by the SQUAR program.

Program SQUAR is the operator request control package. The program is called up when the key "□" is struck. A "□" character is echoed for display on the plasma panel in the position indicated by the cursor. The operator may then enter a five-character command string which is also echoed to the plasma panel. Cursor forward and cursor backspace functions are allowed, but cannot move the cursor out of a range defined by the initial position and the initial position plus five character locations. Any other control function causes the termination of the SQUAR program. Once the operator is satisfied with the string typed, a second "□" is entered. The input string is checked by the system; if recognized, the request is processed; if not the program responds with a "□?", prompting the operator to try again. Once initialized and until terminated, all characters entered are echoed on the panel but are not stored in the displayed page buffer. Normal termination of SQUAR results in clearing the display locations used, and redisplaying the contents of buffer memory. The initial "□" may be entered any where on the panel.

Commands for this system are as presented:

□DAn□ Display the contents of the Alphanumeric page buffer defined by page number n

□DGn□ Display the contents of the Graphics page buffer defined by page number n

□DMn□ Display the content of the alphanumeric page buffer and the graphics page buffer (Mixed) for the page number n.

For the above commands n is assumed to be single digit. Only the least significant digit is examined if a multiple digit is inputted.

If n = 0 or is left blank, the current page will be erased and then rewritten, otherwise the specified page will be selected. Leading, trailing and imbedded spaces are ignored.

□Hnnnn□ - Display the Hologram with frame number nnnn (decimal) for the current displayed page. Leading, trailing, and imbedded spaces are ignored. Leading zero's of nnnn are optional.

□HRES□ Display the computer selected Hologram for the current displayed page.
The "□?" response will be returned if either command implies a frame that is not available on the current tape.

□ALPHA□ Set alphanumeric keyboard mode and write a cursor at the last specified location.

☐ GRAPH ☐ Set track keyboard mode and write a cross "+" at its last specified position.

## a. Alphanumeric Operation

In the Alphanumeric mode, operation of any key except function keys causes a character to be displayed on the screen at the cursor location, the cursor advanced one character location, and the character code to be stored in the corresponding displayed page buffer location. However, if the character location is protected, the new character is not displayed and nothing is stored in the page buffer.

The operations performed by the function keys when in the Alphanumeric mode are described below.

### (1) ENTER

When the ENTER key is depressed, "Attention" status is sent to the external processor. "Attention" may accompany other status conditions depending on the current channel traffic. Response to the "Attention" interrupt is an external processor option.

### (2) SQUARE

The SQUARE key involves the operator request package. See SQUAR for operational description.

### (3) CLEAR

When the CLEAR key on the keyboard is depressed, all nonprotected characters in the displayed page buffer are replaced with spaces, the screen is bulk erased and the page rewritten. All protected characters remain displayed. The cursor position is not affected by this operation.

### (4) LINE ERASE

When the LINE ERASE key on the keyboard is depressed, all non-protected characters on the line specified by the current cursor position are erased and a space character is stored in the corresponding location of the displayed page buffer. The cursor position is not affected by this operation.

(5) <u>Cursor Positioning</u>

Four keys (one each for up, down, right and left) provide for manual cursor positioning. Each key causes the cursor to move a position (a line or a space). The cursor moves only in a given column when either the up ( ↑ ) or down ( ↓ ) key is operated. If on the top line and UP is depressed the cursor moves to the bottom line. If on the bottom line and DOWN is depressed, the cursor moves to the top line.

When the cursor is at the left margin of a line (except the top line) and the LEFT ( ← ) is depressed, the cursor moves to the right margin on the next higher line. If the cursor is at the left margin of the top line, operation of the LEFT key moves the cursor to the right margin of the bottom line.

If the cursor is at the right margin of a line (except the bottom line) and the RIGHT ( → ) key is depressed, the cursor moves to the left margin of the next lower line. If the cursor is at the right margin of the bottom line, operation of the RIGHT key moves the cursor to the left margin of the top line.

(6) <u>CURSOR HOME</u>

Depressing the CURSOR HOME key, moves the cursor to the left margin of the top line, the home position.

(7) <u>CURSOR RETURN</u>

When the CURSOR RETURN key is depressed, all nonprotected characters at and to the right of the cursor location on that line are erased and space codes are stored in corresponding displayed page buffer locations. The cursor is moved to the left margin of the next lower line.

If the cursor is on the bottom line, operation occurs as described above, but the cursor is moved to the left margin of the top line.

(8) <u>CHARACTER INSERT</u>

When the CHARACTER INSERT key is depressed, all characters at and to the right of the cursor position are shifted one space to the right. A space code is written at the cursor position and stored in the corresponding displayed page buffer location. The last character of the line is lost. The CHARACTER INSERT function will not function if there are protected characters at and to the right of the cursor position.

3-8

### (9) CHARACTER DELETE

When the CHARACTER DELETE key is depressed, the character at the present cursor position is erased and all characters to the right are shifted one character location to the left. A space code is written as the last character on the line and stored in the corresponding displayed page buffer location. The CHARACTER DELETE function is inhibited if there are any protected characters at or to the right of the current cursor position.

### (10) LINE INSERT

When the LINE INSERT key is operated, all the characters on the line in which the cursor is located are erased and space codes stored in corresponding displayed page buffer locations. All following lines are shifted down one character line; the contents of the bottom line of the displayed page are lost. The LINE INSERT function is inhibited if there are any protected characters from the beginning of the line in which the cursor is located to the end of the bottom line. The cursor position is not altered by this operation.

### (11) LINE DELETE

When the LINE DELETE key is operated, all characters on the line in which the cursor is located are erased, and all following lines shifted up one character line. The bottom line is erased and space code stored in corresponding displayed page buffer locations. The LINE DELETE function is inhibited if there are any protected characters from the beginning of the line in which the cursor is located to the end of the bottom line. The cursor position is not altered by this operation.

### (12) REPEAT

The REPEAT key when depressed will generate multiple characters or function requests for the next key depressed. All other key operations until REPEAT is released will be ignored. The repeat rate is 3.5 Hz.

### b. Graphic Mode

The Graphic mode is entered only by an operator request for �□GRAPH□. This mode allows an operator to draw lines on the plasma panel and store them in displayed page vector buffer using the alphanumeric board. A cross, which can be moved around the screen, is used to position starting and ending coordinates for the vectors.

The following paragraphs describe the keyboard operation in the graphic mode.

### (1) ENTER

Depression of the ENTER key sends "Attention" status to the external processor. This operation is the same as Alphanumeric mode operation.

### (2) SQUAR

The operation of the SQUAR key involves the operator request package. Operation is the same as in the Alphanumeric mode.

### (3) Cursor Positioning

The four cursor positioning keys UP ( ↑ ), DOWN ( ↓ ), LEFT ( ← ), and RIGHT ( → ) move the cursor cross one element in each of the respective directions.

The keys disignated R, L, U, D, move the cursor cross ten elements right, left, up and down, respectively. The screen appears as a continuous screen to the cross; that is, moving the cross off one edge results in it reappearing on the other edge.

### (4) Start Line

When key S is depressed, the coordinates of the cross position are stored as the starting coordinates for a vector. No visual indication is given.

### (5) End Line

When key E is depressed, the coordinates of the present cross position are stored as the ending coordinates for a vector. Using these coordinates and starting coordinates previously established, the appropriate line is drawn on the screen. The starting and ending coordinates are not stored in the displayed page vector buffer. The ending coordinates are stored in the starting coordinates, so the end of one line becomes the beginning of the next.

### (6) Clear Line

When key C is depressed, the last vector drawn (by an E command) will be selectively erased from the screen. A vector with the same end points but

with the erase bit set is used.  This vector is not stored in the displayed page vector buffer.

### (7) LINE INSERT

When the LINE INSERT key is depressed, the last vector drawn is stored in the next available location in the displayed page vector buffer.

### (8) CLEAR

When the CLEAR key is depressed, the screen is erased, and the displayed page vector buffer is cleared to all nulls.

### 2. Remote Computer Operation

This display system is a multiple buffered, multifunctional computer display. Access to page buffers is controlled by mode selections and page specifications.  A two-byte relative buffer starting location, STLOC, provides random access within these buffers.  Variable length data block transfers are employed, with maximum block size limited by buffer length.  Error indications are returned if the external processor attempts to read/write beyond buffer limits.  Information transferred includes alphanumeric and graphic data, vector formatted and point by point.

The system is designed to operate on the multiplex channel and recognizes 70 (hexadecimal) as its channel address.  Selection priority on the channel is configured for "Select Out".  Multibyte data transfers are performed in control unit forced burst mode.

The following section describes the recognized channel commands and the functions they perform.  Commands sent to the display that are not recognized return "Unit Check" along with device end and channel end status.  "Command Reject" is also set in the sense byte.  If a command is received with incorrect parity, "Unit Check" is again presented with channel end and device end status.  "Bus Out Check" is set in the sense byte.

All data transfers to the display are checked for byte parity.  If a parity error is detected, data transmission is allowed to continue to its normal stopping point, but "Unit Check" is presented with channel end and device end at transmission end.  "Bus Out Check" is set in the sense byte.

Table 3-4 shows a summary of recognized commands.  The commands are discussed in the following paragraphs.

TABLE 3-4.   RECOGNIZABLE COMPUTER GENERATED COMMANDS

| COMMAND NAME | CODE HEX | BLOCK LENGTH | COMMENTS SENDS DATA TO SPECIFIED PAGE |
|---|---|---|---|
| WRITE UNPROTECTED | P1 | Var | Block Length for A/N 1 and A/N2 = 1 1632 bytes<br>61 and 62    6 1536 bytes in multiples of 6<br>A/N 3 on write    2 50 bytes |
| WRITE PROTECTED | P5 | Var | |
| READ MEMORY | P2 | Var | A/N 3 in read    2 bytes |
| READ KEYBOARD | 06 | Var | Waits for ENTER, then sends data<br>Block Size 0 1632/max limited by computer specified cursor position |
| READ SENSE | 04 | 1 | Sense Byte sent to processor |
| STARTING LOCATION | 13 | 2 | Load Starting Location buffer (not changed by any other command) |
| CURSOR POSITION | 23 | 2 | Load Cursor Position Buffer (not changed by any other command) |
| CURSOR RETURN | 8F | 0 | Perform cursor return (see Alphanumeric Mode) |
| CURSOR RETURN PROTECTED | CF | 0 | Same as cursor return but uses protects spaces |
| SET ALPHANUMERIC | 0F | 0 | Sets A/N bit – reset Graphic bit |
| SET GRAPHIC (SET VECTOR) | 1F | 0 | Sets Graphic Bit – Clear A/N bit |
| SET POINTS | 3F | 0 | Set points mode – don't touch A/N or Graphic |

TABLE 3-4. RECOGNIZABLE COMPUTER GENERATED COMMANDS (Continued)

| COMMAND NAME | CODE HEX | BLOCK LENGTH | COMMENTS SENDS DATA TO SPECIFIED PAGE |
|---|---|---|---|
| SET MIXED | 2F | 0 | Set mixed mode – don't touch A/N or Graphic |
| CLEAR SCREEN | 4F | 0 | Bulk erase panel – don't alter any buffer memory or modes |
| SELECT PAGE | P7 | 0 | Display a new page, Page Function of P, A/N, Graphic, Mixed |
| SELECT FRAME | PB | 2 | Send frame address and put it with Page P data. |
| READ FRAME | PA | 4 | Read "sent frame address" and store with Page P data. |

Note:   P refers to Page Number

in Alphanumeric P = [0, 3]

in graphic       P = [0, 2]

A 64-character subset of USASCII-8 is used to transfer alphanumeric data.
Table 3-5 shows the recognized characters and their associated codes. In addition,
reception of code 007 initiates a space to be displayed and a space code to be stored
in the displayed page buffer in place of the 007 code. The 7 x 7 square character
(code 027), which is used by the operator request package, will be displayed on the
plasma if sent by the external processor, but no further function is implied. Use
of this code by the external processor should be avoided in order to eliminate operator
confusion. If a received code is not one of the 66 defined above, it will be treated as
illegal and a heart symbol drawn to indicate its presence. That code remains in
in the displayed page buffer until some operation overwrites it.

### (1) WRITE UNPROTECTED P1

This command transfers data from the external processor to the display.
If the Alphanumeric mode is set, ASCII data is assumed and is transferred to the
alphanumeric page buffer specified by P in the command, starting at the location
specified by the STARTING LOCATION register. The maximum number of bytes that
can be sent without page overflow can be computed as A/N BUFFER LENGTH -
STARTING LOCATION. If P is the displayed page or P is zero, the system displays
the transferred data on the plasma panel.

If the Vector mode is set, data transferred is assumed to be in block
vector format and is stored in the vector buffer specified by the P field of the command.
The starting location within the buffer is the vector location specified by the STARTING
LOCATION buffer. In the vector mode the byte count for a data transfer must be an
integral multiple of six; if not "Unit Check" will be sent with channel end and device
end status and the data will not be displayed regardless of the P field. The maximum
byte count for a data transfer in the mode can be computed as:

$$\text{VECTOR BUFFER LENGTH} - 6* \text{STARTING LOCATION}$$

When no errors are detected during the data transfer, the system will
display the data if the P field specifies the displayed page or is zero. The vector format
is shown in Table 3-6.

If Points mode is set, data is transferred in 3-byte blocks until the
channel count overflows. As each burst is received, channel end status is sent, the
data interpreted as two coordinates of a point is displayed on the panel, and request
is made for the next 3 bytes. When the channel count overflows, the last point is
plotted and channel end, device end status is presented. Table 3-6 also shows the
data format. Points mode is reset when a "Device End" is presented at the device.

TABLE 3-5.  64 CHARACTER ASCII CODE SUBSET

| Column b7 b6 b5 b4 / b3 b2 b1 b0 | 0 0 0 0 | 0 0 0 1 | 0 0 1 0 | 0 0 1 1 | 0 1 0 0 | 0 1 0 1 | 0 1 1 0 | 0 1 1 1 |
|---|---|---|---|---|---|---|---|---|
| 0 0 0 0 | | | Space | 0 | @ | P | | |
| 0 0 0 1 | | | ! | 1 | A | Q | | |
| 0 0 1 0 | | | " | 2 | B | R | | |
| 0 0 1 1 | | | # | 3 | C | S | | |
| 0 1 0 0 | | | $ | 4 | D | T | | |
| 0 1 0 1 | | | % | 5 | E | U | | |
| 0 1 1 0 | | | & | 6 | F | V | | |
| 0 1 1 1 | BELL | 7x7 square □ | ' (apos.) | 7 | G | W | | |
| 1 0 0 0 | | | ( | 8 | H | X | | |
| 1 0 0 1 | | | ) | 9 | I | Y | | |
| 1 0 1 0 | | | * | : (colon) | J | Z | | |
| 1 0 1 1 | | | + | ; | K | [ | | |
| 1 1 0 0 | | | , (comma) | < | L | \ | | |
| 1 1 0 1 | | | - | = | M | ] | | |
| 1 1 1 0 | | | . (period) | > | N | < | | |
| 1 1 1 1 | | | / | ? | O | ⎯ | | |

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TABLE 3-6. VECTOR FORMAT

POINTS MODE DATA FORMAT

BYTE 1   -   8 least significant bits unsigned binary of X coordinate of point

BYTE 2   -   8 least significant bits of unsigned binary of Y coordinate of point

BYTE 3   -   NOT USED

| 8 - 4 NOT USED | E/W | QY | QX |
|---|---|---|---|
| MSB | | | LSB |

QX - Most significant bit of X coordinate

QY - Most significant bit of Y coordinate
E/W - 0 - ERASE THIS POINT
        1 - WRITE THIS POINT

VECTOR MODE DATA FORMAT

BYTE 1   -   8 least significant bits of X starting coordinate

BYTE 2   -   8 least significant bits of Y starting coordinate

BYTE 3   -   8 least significant bits of X ending coordinate

BYTE 4   -   8 least significant bits of Y ending coordinate

BYTE 5   -   NOT USED    W/E   $Q_{YE}$   $Q_{XE}$   $Q_{YS}$   $Q_{XS}$

BYTE 6   -   NONE - NOT USED

$Q_{XS}$ → MSB of X starting coordinate

$Q_{YS}$ → MSB of Y starting coordinate

$Q_{XE}$ → MSB of X ending coordinate

$Q_{YE}$ → MSB of Y ending coordinate

W/E → { 0 - ERASE VECTOR
          { 1 - WRITE VECTOR

Allowable values for the P field, when the Vector mode is set, are P = 0, 1, 2, 3. When P = 3, however, the light pen select function is implied. For P = 0, 1 or 2, data transfers are performed from the vector displayed page buffer, vector buffer 1, or vector buffer 2, respectively. For these transfers the relative starting location is the vector block number specified by the STARTING LOCATION register. The maximum byte count allowed before buffer overflow is flagged can be computed as:

VECTOR BUFFER LENGTH - 6* STARTING LOCATION

If no error conditions are indicated, the system presents channel end device end status, otherwise "Unit Check" status is included with "Command Reject" set in the sense byte.

NOTE: For Commands which use the STARTING LOCATION register, the program checks that the maximum byte count is strictly greater than 0. If this condition is not satisfied, "Unit Check" status with "Command Reject" set in the sense byte is presented with channel end, device end status. Such condition implies that STARTING LOCATION is too large for the defined buffer.

(2) WRITE PROTECTED P5

This command performs the same operation as the write unprotected command except when the Alphanumeric mode is set. A protect bit is added to all the characters transferred by this command.

(3) READ MEMORY P2

This command allows the external processor to read the contents of the page buffers.

When the Alphanumeric mode is set, allowable values for the P field are 0, 1, 2, 3. For P = 0, 1, 2, a data transfer is performed from the alphanumeric displayed page buffer, alphanumeric buffer 1, or alphanumeric buffer 2, respectively.

For these transfers the relative starting location is the relative character location specified by the STARTING LOCATION register. The maximum byte count allowed before page overflow occurs can be computed as:

ALPHANUMERIC BUFFER LENGTH - STARTING LOCATION

Channel end, device end status is presented if no errors are detected, otherwise "Unit Check" will be included with "Command Reject" set in the sense byte.

A P field of 3 regardless of currently set mode specifies the light pen select function. This command causes data in alphanumeric buffer 3 to be interpreted two bytes at a time as character locations where asterisks should be sequentially erased and written. The light pen is enabled. No data is sent to the external processor until an operator selects one of the asterisks. This system returns two bytes of data to the external processor representing the index (0-19) of alphanumeric page 3 whose content was the character location selected by the operator. Attempts to read more than two bytes of data result in "Unit Check" with "Command Reject" set in the sense byte accompanying channel end, device end status. The read page 3 command does not alter the contents of the alphanumeric buffer 3. The external processor may terminate this function by issuing a HALT I/O to the device. "Device End" status will be returned.

### (4) READ KEYBOARD 06

The READ KEYBOARD command sets the keyboard to the Alphanumeric mode regardless of the mode selected by the operator and enters a wait state until the operator depresses the ENTER key. Depression of this key indicates an end of message condition (an exception from the alphanumeric description) and starts a data transfer from the current displayed page alphanumeric buffer starting with the character location indicated by the last external processor specified cursor position, CRPOS.

Channel stop is the normal end of transmission, with channel end and device end returned, otherwise a page overflow terminates the transfer and "Unit Check" status is presented along with the normal ending status. "Command Reject" is set in the sense byte for this condition. The maximum transferred byte count before overflow occurs can be computed as:

$$ALPHANUMERIC\ BUFFER\ LENGTH - CRPOS$$

The processor specified cursor position, CRPOS, is not modified by this command, nor can it be modified by any operator action. The external processor may terminate this function by issuing a HALT I/O to this device. "Device End" status is presented in response.

### (5) READ SENSE 04

The READ SENSE command sends one byte of data to the external processor giving detailed device status. Bit assignments conform to standard IBM System/360 sense by the assignments. Channel end and device end status is sent at the completion of the transfer. If the external processor attempts to read more than one byte, "Unit Check" with "Command Reject" will accompany normal ending status.

### (6) STARTING LOCATION 13

The STARTING LOCATION command allows the external processor to random access within the data buffers of the display system. When the device decodes this command, it will request two bytes of data to be sent from the processor to the starting location register STLOC. The first byte sent should be the high order byte of a half word binary number, the second the low order byte. If the processor does not indicate a channel stop condition after two bytes have been sent, the device will present "Unit Check" with "Command Reject" set in the sense byte along with normal channel end and device end status. Values of the STARTING LOCATION listed in Table 3-7 are permissible. Values outside these limits may result in a "Unit Check" status condition on subsequent data transfers to and from the display buffers.

### (7) CURSOR POSITION 23

When the CURSOR POSITION command is received, the display system requests the external processor to send two bytes of data to the cursor position buffer CRPOS. The first byte sent should be the most significant byte of a half word binary number, the second byte sent should be the least significant byte of the half word. Care should be taken that the number sent does not exceed 1631 (decimal) as larger cursor positions are undefined. The system moves the alphanumeric cursor to the location specified by CRPOS. Channel end and device end are the normal ending status conditions, however, if the processor does not indicate a channel stop condition after the second byte is transferred, "Unit Check" status, with "Command Reject" set in the sense byte, will accompany the ending status presentation and the cursor will not be moved.

TABLE 3-7. ALLOWABLE STARTING LOCATIONS

| Mode | Starting Location Minimum Value | Starting Location Maximum Value |
|------|---------------------------------|---------------------------------|
| Alphanumeric Mode – Pages 1 & 2  Read & Write Operations | 0 | 1631 |
| Alphanumeric Mode – Page 3  Write  Not Applicable on Read | 0 | 18 |
| Vector Mode – Pages 1 & 2  Read & Write | 0 | 254 |

(8) CURSOR RETURN 8F

The detection of a CURSOR RETURN command instructs the display to perform the carriage return function. No data is transferred with the command. Channel end and device end status is presented.

(9) CURSOR RETURN PROTECTED CF

This command performs the carriage return function, except that space codes stored in memory have the protection bit set.

(10) SET ALPHANUMERIC 0F

The SET ALPHANUMERIC command sets the alphanumeric bit and clears the vector bit in the transfer mode. Channel end and device end status is presented.

(11) SET VECTOR 1F

The SET VECTOR command sets the vector bit and clears the alphanumeric bit in the transfer mode. Channel end and device end status is presented.

(12) SET MIXED 2F

The SET MIXED command sets the mixed bit in the transfer mode. No other bits are affected. Channel end and device end status is presented.

(13) SET POINTS 3F

The SET POINTS command sets the points bit in the transfer mode. No other bits are affected. Channel end and device end status is presented. The Points mode causes the next WRITE data transfer to be received in three-byte bursts and plotted on the plasma panel.

(14) CLEAR SCREEN 4F

Reception of this command instructs display system to bulk erase the plasma panel. No memory buffer contents or display modes are affected. Channel end and device end status is presented.

### (15) SELECT PAGE P7

When the SELECT PAGE command is received, the unit bulk erases the plasma panel and displays the page or pages specified by the P field of the command and the state of the transfer mode. Acceptable values for the P field are 0, 1, 2; other values will cause "Unit Check" with "Command Reject" set in the sense byte to accompany the normal channel end and device end status. Table 3-8 shows the possible combinations.

### (16) SELECT FRAME PB

The SELECT FRAME command allows the external processor to call up a frame address from the system projection unit. Detection of this command directs the unit to transfer two bytes from the external processor to the frame buffer for the page specified by P. P = 0 causes the current displayed page number to be used by default. The first byte transferred should be the most significant byte of a binary half word, and the second byte the least significant. Setting the most significant bit of that half word will instruct the system to prevent the operator from changing this frame. If the processor does not indicate a channel stop condition after the second byte is transferred, a "Unit Check" will accompany the normal channel end and device ending status, and no attempt is made to select the frame. If the data transferred is to be frame buffered for the displayed page, the device will try to select the frame specified by the processor. If the frame is not available, "Unit Check" status will be returned with channel end and device end.

### (17) READ FRAME PA

The READ FRAME command directs the display system to send four bytes of data to the external processor from the frame buffer defined by the P field of the command. A zero P field implies the current displayed page number.

The first two bytes sent comprise the processor requested frame number with the most significant byte sent first; the next two bytes sent reflect the actual frame address selected, the last time that the page specified by P was active. The most significant bit of the "Actual Frame" (MSB of Byte 3) is set when frame selected is the result of a SELECT FRAME command or an operator request through the SQUAR package. If the processor attempts to read more than four bytes of data, "Unit Check" status with "Command Reject" set in the sense byte will accompany the normal ending status, channel end and device end.

TABLE 3-8.  SELECT PAGE COMMANDS

| | A/N | Vector | Mixed | Function |
|---|---|---|---|---|
| 0 | 1 | 0 | 0 | Current Alphanumeric page redisplayed. |
| 1 | | | | Page 1 Alphanumeric displayed. |
| 2 | | | | Page 2 Alphanumeric displayed. |
| 0 | 0 | 1 | 0 | Current Vector buffer redisplayed. |
| 1 | | | | Page 1 Vectors displayed. |
| 2 | | | | Page 2 Vectors displayed. |
| 0 | 1 | 0 | 1 | Alphanumeric and Vectors for current page number displayed. |
| 1 | | | | Alphanumeric and Vectors for Page 1 |
| 2 | | | | Alphanumeric and Vectors for Page 2 |
| 0 | 0 | 1 | 1 | Vectors and Alphanumerics for current page number displayed. |
| 1 | | | | Vectors and Alphanumerics for Page 1 |
| 2 | | | | Vectors and Alphanumerics for Page 2 |

The mixed mode bit of the transfer mode is reset by the execution of
SELECT PAGE.

### 3. Plasma Panel Controller

The Plasma Panel Control is the interface between the Nova I/O system and the Plasma Drive Electronics. This control unit provides storage for the X and Y display coordinates, hardware character generation for the parallel drive electronics, blinking and auroon. The circuit diagrams for this panel are presented in Appendix I.

The interface occupies one subassembly slot and is wired for installation in SLOT 17. The commands for this interface are shown below.

DEVICE CODE 35, OCTAL

"Busy" and "Done" are sensed by bits 8, 9 in all I/O instructions.

DOA N,35     Loads Command/Character register from accumulator N

Accumulator bit: 0,1, not used

| | | |
|---|---|---|
| | 2 | Light Pen Enable |
| | 3 | Not used |
| | 4 | Bulk Erase |
| | 5 | Parallel Mode/Serial Mode |
| | 6 | Write/Erase |
| | 7 | Character/Cursor |
| | 8 | Not used |
| | 9-15 | 7 bit ASCII Character scale |

DIA N,35     Reads light pen flag to accumulator N – AC bit 0 –
Light Pen Detect. Bits 1-15 not used.

DOB N,35     Loads X-address register from accumulator N bits 7-15.
Bit 15 of ACC is LSB of X-address.

DOC N,35     Loads Y-address register to accumulator N bits 7-15.
Bit 15 of AC is LSB of Y-address.

START:     Sets "Busy", Clears "Done"

CLEAR:     Clears "Busy", Clears "Done", Clears Control Registers

PULSE:     Sets Cursor Blink Inhibit

IORST:     Resets all Logic to Active Wait State

Setting "Busy" causes the panel controller to perform the operation specified by the command/character register. At the completion of the operation, the controller clears "Busy" and sets "Done". The interrupt facility is not used by this device.

For parallel commands (command/character register bit 5 = 1), "Done" sets 150 $\mu$s after setting "Busy". For serial commands (command/character register bit 5 = 0), "Done" sets 20 $\mu$s after setting "Busy". These times can vary $\pm 10\ \mu$s, depending on the time required to synchronize with the plasma panel cycle. Multiple Bulk Erase commands, however, will not be performed more often than every 400 $\mu$s.

Any instruction to the display controller should be preceded by NIOP before "Busy" or "Done" is checked. This insures that no interference with the cursor will occur, a clear pulse MIOC should be issued to remove the effect of the cursor inhibit.

| EXAMPLE: | NIOP 35 | ; | Set Cursor Inhibit |
|----------|----------|---|---------------------|
|          | SRPBZ 35 | ; | Panel Busy ? |
|          | JMP. -1  | ; | Yes – Wait |
|          | NIOC     | ; | No – Clear Cursor Stop |
|          |          | ; | OK to Continue |

Enabling the light pen allows the light pen flag to be set and can be read by a DIA N, 35 instruction. Once set, a clear pulse is required to reset this flag.

Bits 5, 6 and 7 of the command/character register control the major cycle of the controller. Table 3-9 shows the possible combinations.

TABLE 3-9. COMMAND/CONTROL REGISTER CODING

| b5 | b6 | b7 | |
|----|----|----|---|
| 0 | 0 | X | Erase a Point } Character Code Ignored |
| 0 | 1 | X | Write a Point |
| 1 | 0 | 0 | Erase a Cursor |
| 1 | 0 | 1 | Erase a Character Block } Character Code Ignored |
| 1 | 1 | 0 | Write a Cursor |
| 1 | 1 | 1 | Write Character with Code in B7–B15 |

A bulk erase of the plasma panel is controlled by command/character register bits 4 and 6. Bit 4 must be set and bit 6 must be zero. If bit 6 is nonzero, bit 4 is ignored.

### 4. Keyboard Controller

The keyboard control interfaces a Micro-Switch K52125-71SW1Z keyboard to the Nova I/O Bus System. The controller requires a 7.5-Hz pulse input for the REPEAT function to operate and a -12 Vdc @ 5 mA source. Both of these signals are made available from the Plasma Panel Control Unit. This controller occupies half of a subassembly slot, and is wired for installation in SLOT 16.

One I/O instruction is recognized to retrieve data from the 7-bit buffer in the controller. "Done" is controlled and sensed by bits 8 and 9 in all I/O instructions with device code 36. "Interrupt Disable" is controlled by interrupt priority mask bit 11.

DIAX N,36     Read the contents of the interface register into ACN bits 7-15, and perform the function specified by X. Clear ACN bits 0-8.

When the operator strikes a key, the character code is loaded to the interface buffer register and "Done" sets, requesting an interrupt if "Interrupt Disable" is clear. All further key operations are ignored until the program restarts the controller by clearing "Done" with a START pulse.

### 5. Holographic Projector Controller

The Holographic Projector Control interfaces the Nova I/O Bus to the Holographic projector drive control electronics. This interface provides frame buffer storage and the control signals for the projector drive. Physically the interface shares one subassembly board with the keyboard controller, and is configured for installation in SLOT 16.

Two I/O instructions are recognized to send and receive data of a bit interface register. "Busy" and "Done" are controlled or sensed by bits 8 and 9 in all I/O instructions with device code 37. "Interrupt Disable" is controlled by interrupt priority mask bit 12.

DOAS N,37     Load the interface register with the contents of ACN bits 4-15 and start the interface.

NOTE: Give the start pulse with the DOA instruction or the interface will hang up.

DIAX N, 37  Transfer the contents of the interface register to ACN bits 4-15. Clear bits 0-3. Perform the function specified by X.

    Setting "Busy", Start, causes the controller to initiate a selection sequence for the frame address specified by the interface buffer register. Independent hardware in the projector drive electronics determines the availability of a particular frame, if rejected it will be done at initial selection time. Frame reject or frame found completes the operation clearing "Busy" and setting "Done", requesting an interrupt if "Interrupt Disable" is clear. Clearing "Busy", CLEAR, stops the selection sequence. If the control is "Busy" or "Done", the manual motor drive lines are inhibited. The program can inhibit manual motion with a NIOP instruction setting manual inhibit. A clear pulse is necessary to clear manual inhibit.

### 6. Flow Chart Listings

    Reproducible detailed flow charts were delivered with the Multifunction Display System. Table 3-10 lists the major modules of the flow chart package. The program modules were detailed extensively with the intent of eliminating the requirement for further description. Consequently only brief summary descriptions of selected flow chart modules are present in the following paragraphs of this section where it is felt additional clarification may be useful.

### a. H4025 – 360 Interface Driver

    Subroutines .XSTAT, .RECV, .XMT of the module H4025 have several exceptional return conditions. The flow charts do not show these returns as in all cases the same action is taken. Only the common or normal return is indicated. The following paragraphs describe the exception conditions and the action taken in their event.

(1) .XSTAT

    Subroutine .XSTAT can perform three returns:

    Return 1 will not happen in this system. Any return here results in a processor halt.

    Return 2 is taken if a System Reset or Selective Reset for the current channel address has been issued. All programs calling .XSTAT will perform the .CLR subroutine if return 2 is taken.

    Return 3 is the normal return, and is the one assumed in the flow charts where .XSTAT is referenced.

## TABLE 3-10. FLOW CHART LIST

| Module Name | Major Functions |
|---|---|
| INTPR | Interrupt processing and power restart |
| INITI | Initialization routines, page buffers and tables |
| SSUBR | Service Subroutines |
| DISPL | Panel Display (Alphanumerics) |
| H4025 | 360 Interface Driver |
| CMDPR | Command Decoder and Command Processing |
| SLFAM | Holographic Projector Driver |
| KBDSR | Keyboard Input Decoding and Display |
| ENTER | Attention status |
| SQUAR | Operator Request Package |
| EDIT 1 | Cursor Control |
| EDIT 2 | Edit Functions |
| CLEAR | Memory Clear |
| GSPAC | Panel Display (Graphics) |
| SELECT | Page Switching |
| ADRES | Page Table Hookup |
| TRACK | Operator Graphics Input |
| COMSR | System Utilities |
| HLGSR | System Utilities |
| SVC | System Utilities |

(2)   .RECV, .XMT

Subroutines .RECV, .XMT have five defined return conditions:

Return 1 for CALLS TO .RECV indicate a data parity error, all programs branch to "DPAR" when this return is taken. For calls to .XMT, the processor will halt when this return, as a probable hardware failure, is indicated.

Return 2 is taken when a system reset or a selective used for the active channel address has been issued. All programs call subroutine .CLR under this circumstance.

Return 3 is performed when the channel issues a HALT I/O. All routines branch to HIO, which sends "device end" status, when Return 3 is taken.

Returns 4 and 5 are the normal exits from either .RECV or .XMT. Return 4 is performed when the channel count overflows (channel stop) and Return 5 is taken when the Nova count overflows.

In the case when channel stop and Nova count overflow occur simultaneously, Return 4 is taken; the flow charts show which return condition, return 4 or return 5, is used.

b. CMDPR – Communications Processor

The communications processor interprets channel commands, establishes parameters for data transfers and returns necessary status information to the internal processor. This module (CMDPR) is initially entered in response to a H4025 interrupt. Any entry into CMDPR causes the current mode of the operator's keyboard to be suspended and ENTER ONLY mode to be set.

A subroutine designed to search the COMMAND table for new commands (.CTSRH) is called as a reception of a new command is one of the possible entry conditions. If .CTSRM finds a command in the table, control is passed to the command decoder. This module checks if the new command matches with any of the entries in the Command Specification Table (CST); if so, control is transferred to the module whose entry point is defined in a corresponding displacement in the Service Routine Table (SRT). If the command recognized is Hex "FF", a command parity condition is indicated; if the command is not recognized at all, a command reject condition is set. In both of the above circumstances "Unit Check" status is returned to the external processor.

At the completion of any commanded function .CTSRH is called again in the event command chaining was specified. If a new command is returned, the procedure described above is executed again and continues to do so until chaining is no longer specified, at which time .CTSRH will take the second return. Since the external processor has completed a command sequence, the "off line request flag" is checked and the device is set off line if the operator has requested to do so. In either case, the operator keyboard made active when CMDPR was entered is reestablished and CMDPR is returned to an idle state, awaiting for the initialization of a new command sequence.

## (1) Communications Processor Command Tables

Command Specifications Table defines the legal channel command codes. The right byte of each entry specifies the command code, and the left byte specifies the mask to be used on the command in question. The masks allow both 4-bit and 8-bit comparisons to be made. The related Service Routine Table defines entry points of the particular service routines for each command.

| CST | | SRT |
|---|---|---|
| MASKP | 01 | WRIUN |
| MASKP | 05 | WRIPR |
| MASKP | 02 | RDMEM |
| MASKP | 06 | RDKBD |
| MASKN | 04 | RDSEN |
| MASKN | 03 | STLOC |
| MASKN | 13 | CRLOC |
| MASKN | 8F | CRONP |
| MASKN | CF | CRPRO |
| MASKN | 0F | ALPHA |
| MASKN | 1F | GRVEC |
| MASKN | 3F | GRPTS |
| MASKP | 07 | SELPG |
| MASKP | 0B | SLHOL |
| MASKP | 0A | RDHOL |
| MASKN | FF | CMDPR |
| 00 | 00 | CMDRE |

CST is terminated by a zero word, the corresponding entry is command reject. Commands in CST are in hexadecimal.

## (2) Page Specification Tables

The Page Address Table is built at initialization time. When full initialization is performed ("START" specified as beginning address) the user must make sure that Location 404 reflects the highest used memory address for .NREL code. This location is maintained by the DGC relocatable loader.

| DISPLACEMENT IN TABLE | DATA |
|---|---|
| 0 | ALPHANUMERIC PAGE 1 START |
| 1 | VECTOR PAGE 1 START |
| 2 | PROJECTOR PAGE 1 START |
| 3 | ALPHANUMERIC PAGE 2 START |
| 4 | VECTOR PAGE 2 START |
| 5 | PROJECTOR PAGE 2 START |
| 6 | "*" START (A/N PAGE 3) START |
| 7 | DUMMY |
| 10 | DUMMY |

(3) Page Length Table

The Page Length Table is used during full initialization in building the page address table, and in all operations involving the communications processor to determine available buffer length.

| DISPLACEMENT | DATA |
|---|---|
| 0 | LENGTH ALPHANUMERIC PAGE 1 (BYTES) |
| 1 | LENGTH VECTOR PAGE 1 (BYTES) |
| 2 | LENGTH PROJECTOR PAGE 1 (BYTES) |
| 3 | LENGTH ALPHANUMERIC PAGE 2 (BYTES) |
| 4 | LENGTH VECTOR PAGE 2 (BYTES) |
| 5 | LENGTH PROJECTOR PAGE 2 (BYTES) |
| 6 | LENGTH "*" BUFFER (BYTES) |
| 7 | 0 |
| 10 | 0 |

"Offset" is defined as the displacement between corresponding entries in the above two tables for ease in processing.

The following fixed format two-byte buffers are also defined:

| | |
|---|---|
| RSLOC | Relative page Starting LOCation |
| SENSE | SENSE Byte |
| PENSL | Light PEN SeLected location |
| TMODE | Communication Transfer MODE |
| DMODE | Display MODE |
| CRPOS | Computer Selected CursoR POSition |

(4) TMODE

TMODE reflects the current state of the communications processor. Data received and transmitted over the channel is processed (stored, edited, displayed) based on current TMODE parameters. The external processors control TMODE.

FORMAT:

| | |
|---|---|
| Bits 0-11 | Not Used |
| Bit 12 | MIX |
| Bit 13 | VECTOR |
| Bit 14 | ALPHANUMERIC |
| Bit 15 | POINTS |

Bit 12. MIX will control the display of transferred data; at the subsequent SELECT PAGE command MIX is reset upon completion of the "SELECT PAGE" operation.

Bit 13. VECTOR informs the communications processor to interpret all subsequent data transfers as blocked vector information. Data is transferred to the appropriate vector buffer area.

Bit 14. ALPHANUMERIC allows the communications processor to interpret all subsequent data transfers as ASCII characters. Data is transferred to the appropriate character buffer area.

Bit 15 POINTS. The next data transfer is non-buffered, and will be in three-byte busts. The communications processor will interpret these three bytes as coordinates to be displayed. Data will be transferred until the external processor indicates an end condition. POINTS is reset at this time.

(5) DMODE

DMODE reflects the current displayed page. DMODE can be changed by operator request or by external processor command (SELECT PAGE)

FORMAT:

| | | |
|---|---|---|
| BITS 0-9 | Not used | |
| BITS 10-13 | Logical Page Number | |
| Bit 14 | VECTOR | Data Displayed |
| Bit 15 | ALPHANUMERIC | Data Displayed |

Bits 14 and 15 will both be set by the command sequence

SET MIXED

SELECT PAGE N

or by an operator request

"◻ DMn◻ "

c. SQUAR Program Description

Program initialization is the routine SQUAR. A switch on the keyboard mode decoder is set to route subsequent input to SQR. 2. As characters are input, they are stored in the string buffer based on the displacement between the current cursor positions and the initial cursor positions. When SQR. 2 recognizes as "◻" it searches the string buffer and forms two new strings ACMD and ANUM. The word ACMD contains, in a patched format, the characters, ignoring spaces, found in the string buffer. The word ANUM contains a BCD number formed by digits found in the string buffer. ACMD is then compared with entries in the table LIST for a possible match. If one exists, the routine whose entry point is specified by a corresponding entry in table .TDSP is given control; otherwise the programs informs the operator of no selection with a "◻ ?" response.

Error returns, ("◻ ?") are possible from routines specified by .TDSP. For example, SQUAR accepts the command HANND; but the module that selects the frame determines the validity of the requested frame address. If it finds that the frame address is unacceptable it will perform an error return and the "◻ ?" response will be given.

The operator keyboard service routine first examines the word SMASK to determine which codes are acceptable input. The recognized states of SMASK and their bit configurations are:

| | |
|---|---|
| ENTRY ONLY | 100000 |
| TRACK | 020000 |
| ALPHANUMERIC | 010000 |
| READ KEYBOARD | 004000 |

The service routine examines the received character code to see if the ENTER key was struck; if so, control is passed to the enter mode for further processing; if not, SMASK is examined to see if ENTER ONLY is set; if so, the routine takes its normal return without any further processing of the received character, otherwise the routine operates as if in the alphanumeric mode.

If READ KEYBOARD is the active mode, the program checks to see if ASCII code 027, the operator request delimiter, was input; no action is taken if this is the case; otherwise this mode operates just like the alphanumeric mode. If neither ENTER ONLY nor READ KEYBOARD is set, this routine checks if the operator request package has been previously activated. If so control is passed to SQR. 2 for processing and interpretation; if not the program continues and checks if Alphanumeric mode is set.

When Alphanumeric mode is the current mode, all input codes are allowed. Control codes are detected by bits 6 and 7, both zero, and control is passed to section of the program to decode them. Table 3-11 defines the recognized control codes and their functional assignments. Character code assignments are conventional ASCII. They are written on the plasma panel at the current cursor position and stored in the appropriate memory buffer location if that location has not been protected by the external processor. The cursor is then advanced to the next character location and the normal routine exit is taken.

Track is a special keyboard mode used to generate and store vector information. A cross (+) is used as a cursor in this mode. The normal alphanumeric cursor positioning keys move the cross plus or minus one element along each axis. Screen wraparound is employed; the next address beyond $511_{10}$ is $0_{10}$, and the address below $0_{10}$ is $511_{10}$. Alphanumeric keys, R, L, U, D will move the cursor ten elements right, left, up, and down, respectively. Key S (start) instructs the system to use the present cross position as an initial vector point, Key E (end) instructs the system to use the present cross position as a vector and point, draw the vector in the plasma panel using the previously defined starting point, and set the current end point as the new starting point.

TABLE 3-11.  KEYBOARD FUNCTIONS

---

Function Keys

    ENTER                               CHARACTER DELETE
    CLEAR                                LINE INSERT
    LINE ERASE                        LINE DELETE
    CURSOR POSITIONING (4 KEYS)     REPEAT
    CURSOR HOME                     SQUARE
    CURSOR RETURN
    CHARACTER INSERT

Holographic Retrieval

    FAST FORWARD                  UP
    FAST REVERSE                  DOWN
    SLOW FORWARD
    SLOW REVERSE

SQUARE FUNCTIONS (Used with square function key)

| □DAn□ | Displays Alphanumeric page n; n = 1, 2 |
|---|---|
| □DGn□ | Displays Graphical page n; n = 1, 2 |
| □DMn□ | Display Mixed Alphanumeric and Graphical data<br>  n = 1, 2 |
| □H nnnn□ | Display holographic frame  nnnn |
| □HRES□ | Display computer selected page |
| □ALPHA□ | Set alphanumeric mode |
| □GRAPH□ | Set graphical mode |

LINE INSERT will store the last vector drawn in the next available slot of the display page vector buffer. (Vectors are stored in the buffer by the external processor based on the RSLOC parameter and are flagged to indicate that they are there. Track will not overwrite external processor generated vector data).

d. SELECT

Description: Displays Alphanumeric and Graphic pages on command.

Calling Sequence: CALL SELECT
ADDRESS OF LOGICAL PAGE #
ADDRESS OF MODE CONTROL
ERROR RETURN
NORMAL RETURN

Input: Address of a logical Page # specification contents in Bits 12-15

Address of mode control word – format of TMODE is used

Outputs: New displayed page

DMODE updated to reflect display status

TMODE control/mixed bit is reset.

Error Return is taken if address data for logical page/request mode doesn't exist. DMODE reflects current screen display.

e. ADRES

Description: ADRES looks up page data from DATAB, PLTAB based on information passed in ACO at CALL

Calling Sequence: CALL ADRES
ERROR RETURN
NORMAL RETURN

Inputs:

| ACO | B0 | B1 | B1 | | $B_{11}$ | $B_{12}$ | $B_{13}$ | $B_{14}$ | $B_{15}$ |
|-----|----|----|----|----|---------|---------|---------|---------|---------|
| | | | | Next Word | | | | | |

B0, B1        PAGE TYPE

B11-B15        PAGE NUMBER

| PAGE TYPE | B0 | B1 |
|-----------|----|----|
| ALPHANUMERIC BUFFER | 0 | 0 |
| PROJECTOR FRAME BUFFER | 0 | 1 |
| VECTOR BUFFER | 1 | X |

Output:     PAGE NUMBER = 0     DATA FOR DISPLAYED PAGE RETURNED

Buffer starting address returned in AC0

Buffer length returned to AC1

Comments:     Error Return is taken if either Page Starting Address or Page Length is zero.

No AC's are preserved.

f.    GRAPH

Calling Sequence:     CALL GRAPH

BUFFER POINTER

VECTOR COUNT

RETURN

Buffer Pointer to beginning address of three word vector blocks. Graph returns when vector count goes to zero.

Graph does not modify buffer contents.

g.   Vector Generator

The vector generator module "Graph" computes and displays the points of a line if given the end points. The data used by "Graph" is formatted so that the end points never specify a line or part of a line outside the 512 x 512 element active area. See Table 3-12 for vector storage format. Figure 3-2 shows the coordinate definitions.

The vector generator computes points such that from a given displayed point on a line the next point which is displayed is one of the eight points surrounding the known point. This guarantees that the line drawn will contain the maximum number of points.

To handle the arithmetic for this operation, it is convenient to work with a line slope less than one. When one axis is incremented (or decremented) by one and the other axis is incremented (or decremented) by less than one, the computer point is never further than one element away.

Consider a case where the slope of a line, computed as the ratio of delta y and delta x, is less than one. One register mapped to the x-axis of the display is changed by one each step. Another register is changed by the value of the slope each step. The contents of this register is half rounded and displayed on the y-axis of the display. This procedure can be executed for the necessary number of steps until the endpoint is reached.

In cases where the slope, normally computed, is greater than one; take the inverse of the slope, use that value and repeat the previous procedure; only swap the assignment of the registers prior to displaying the point.

Implementation of this mechanism only involves knowing if the slope is less than or greater than one, if greater take the inverse and remember to swap axes before write or erasing a point.

C.   PLASMA PANEL SUBSYSTEM*

Alphanumeric and graphical information is presented on the 512 x 512 60-line/ inch dot matrix transparent plasma panel (Fig. 3-3). The panel, which may be operated in either a serial or 16-bit parallel mode, is constructed by Owens-Illinois. The parallel drive mode of operation was developed for use with the Multifunction Display System.

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*This section is excerpted from Owens-Illinois Technical Report #72-019, "Operational Description of the Digivue Display/Memory Unit 512-60"; R. J. Abbott, Jr., and D. E. Liddle, September 15, 1972.

## TABLE 3-12. VECTOR FORMAT

| | |
|---|---|
| BYTE #1 | Eight least significant bits of the X-starting coordinate |
| BYTE #2 | Eight least significant bits of the Y-starting coordinate |
| BYTE #3 | Eight least significant bits of the X-ending coordinate |
| BYTE #4 | Eight least significant bits of the Y-ending coordinate |
| BYTE #5 | Quadrant Spec |
| | LSB – Quadrant of X-starting coordinate |
| | Quadrant of Y-starting coordinate |
| | Quadrant of X-ending coordinate |
| | Quadrant of Y-ending coordinate |
| | Write = 0, Erase = 1 |
| BYTE #6 | Null |
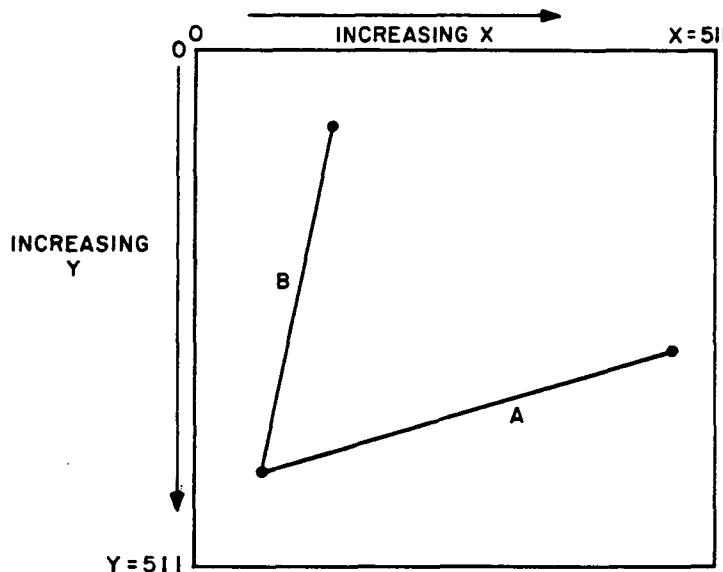


Fig. 3-2. Vector coordinate definition.

Fig. 3-3. Plasma panel and keyboard.

In the serial mode, the display matrix is addressed one point at a time and requires approximately five seconds to address all points in the display. The parallel mode of operation allows the simultaneous addressing of all points in a 16-point high column and requires approximately 330 milliseconds to address all points. In either mode, the display may be addressed at a rate of up to 50,000 operations per second.

For operation, the display unit accepts from the control subsystem an X and Y address of nine bits each, 16 parallel address inputs, write, erase, bulk erase, and mode signals.

A status output from the display unit is provided which indicates when the display may be addressed.

1. <u>Input Signal Requirements</u>

The following is a listing of signals which are routed at connectors J2 and J3 on the rear of the plasma panel display module.

<u>J2 CONNECTOR</u>

| <u>Pin</u> | <u>Description</u> |
|---|---|
| 1 thru 9 | Binary X address input ($X_0$ thru $X_8$) |
| 10 thru 18 | Binary Y address input ($Y_0$ thru $Y_8$) |
| 19 | Write operational input |
| 20 | Erase operational input |
| 21 | Bulk erase operational input |
| 22 | Status signal output |
| 23 | Signal ground |
| 24 & 25 | N/C |

<u>J3 CONNECTOR</u>

| <u>Pin</u> | <u>Description</u> |
|---|---|
| 1 thru 16 | Parallel address inputs ($P_0$ thru $P_{15}$) |
| 17 | Mode operational input |
| 18 thru 20 | N/C |
| 21 | Power supply earth ground |
| 22 | Display chassis ground |
| 23 | Logic +5V dc* |
| 24 & 25 | Signal ground |

All input signals except parallel address and mode inputs are internally terminated by 1000 ohms to ground. All input and output signals are positive logic, TTL compatible.

<u>AC power must be removed from the display unit power supply before making or breaking any power or signal connectors.</u>

The X and Y address inputs accept the pure binary address for the point to be written or erased. (In parallel operation, up to 16 points may be written or erased at once in the Y axis). When in the parallel mode, only bits $Y_4$ through $Y_8$ of the Y address are used to select one of 32 sectors, each of which is comprised of 16 consecutive horizontal electrodes. The X address selects one column of 16 points in the addressed sector. The parallel address inputs are then used to address any number of the 16 points in the selected sector column.

*provided for test purposes only

Serial operation utilizes all X and Y address inputs to address the display matrix. The parallel address inputs have no effect in this mode.

The write, erase, and bulk erase inputs are normally held at logical "0". A logical "1" present at the write input will turn on the point (points in parallel mode) selected by the data at the address inputs. Similarly, a logical "1" at the erase input will turn off the point or points selected. The simultaneous presence of a logical "1" at both the erase and bulk erase inputs will result in the turning off of all points that have been written in the display panel without regard for the data at the address inputs. The display unit is internally limited so as to allow a bulk erase at a maximum rate of every 400 microseconds.

The status output is provided so that the input signals may be properly synchronized with the operation of the display unit. In the rest state, i.e., the write, erase, and bulk erase (operational signals) are all at logical "0", the status line will reset at a logical "1" level. Within 20 microseconds after the presentation of an operational signal, the status line will change to logical "0" and remain there until the operation called for by the operational signal is completed, at which time it will return to logical "1". The status signal will drop to logical "0" again in 2 microseconds if an operational signal is still present, or is presented within 2 microseconds of the "0" to "1" transition of the status signal. (See Fig. 3-4.) The operational inputs may change after the status output falls to logical "0".

Valid address data must be present at the address inputs whenever the write or erase inputs are raised. This address must remain valid from the time when the status output falls to a logical "0" until it returns to a logical "1". Only after the "0" to "1" transition of the status signal may the address inputs be changed (see Fig. 3-4).
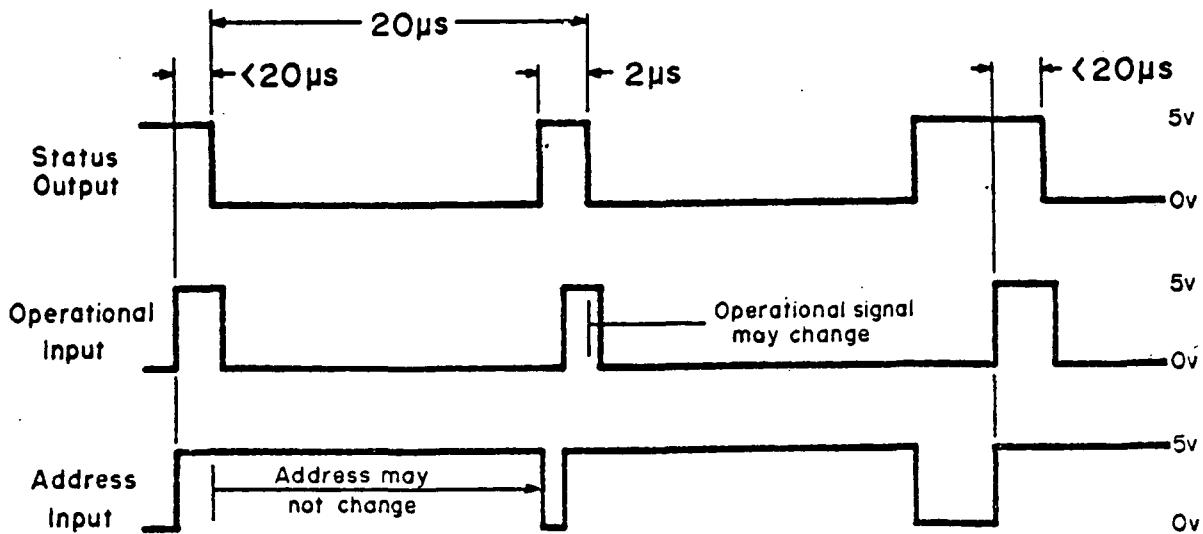


Fig. 3-4. Plasma panel, input signal timing.

For fully synchronous operation, i.e., the addressing of the display unit such that it operates at its maximum speed, the address must be updated and the appropriate operational input raised to logical "1" within 2 microseconds after the "0" to "1" transition of the status output signal. For continuous write or erase operation, the appropriate operational signal may be held in a logical "1" state while only the address inputs are updated during the 2 microseconds.

A logical "1" at the mode input will select parallel operation of the display unit while a logical "0" will select serial operation. The mode input may be changed concurrently with the address data.

### 2. Operational Description

#### a. Energy Circuits

The energy circuits for the Plasma Panel Subsystem consist of the sustainer, which supplies the necessary waveform to sustain the discharges in the display panel; the diode switch and resistor pulser, which modify the basic sustainer waveform to cause one or more points in the display panel to be written or erased; and the diode-resistor matrix, which serves as the junction between the display panel, sustainer, diode switch, and resistor pulser and, along with the latter two circuits, serves as the multiplexer to address individual points on the display panel.

Each axis of the panel, X and Y, has associated with it a set of these circuits. The circuits associated with the Y axis are essentially the same as those of the X axis and differ primarily in the polarity of components and only slightly in operation. Therefore, only the Y axis circuits will be described and the manner in which they differ from the X axis circuits will be noted.

#### b. Sustainer

The sustainer circuits produce the basic waveform required to sustain the discharges in the display panel (Fig. 3-5c). Each sustainer printed circuit board, of which there are two in the display unit, contains three individual sustainer circuits. In each axis, one of these circuits is associated with the odd electrodes, another with the even electrodes, and a third with the borders. All sustainer circuits produce essentially identical waveforms, the main difference being that the X axis waveforms are 180 degrees out of phase with those of the Y axis.
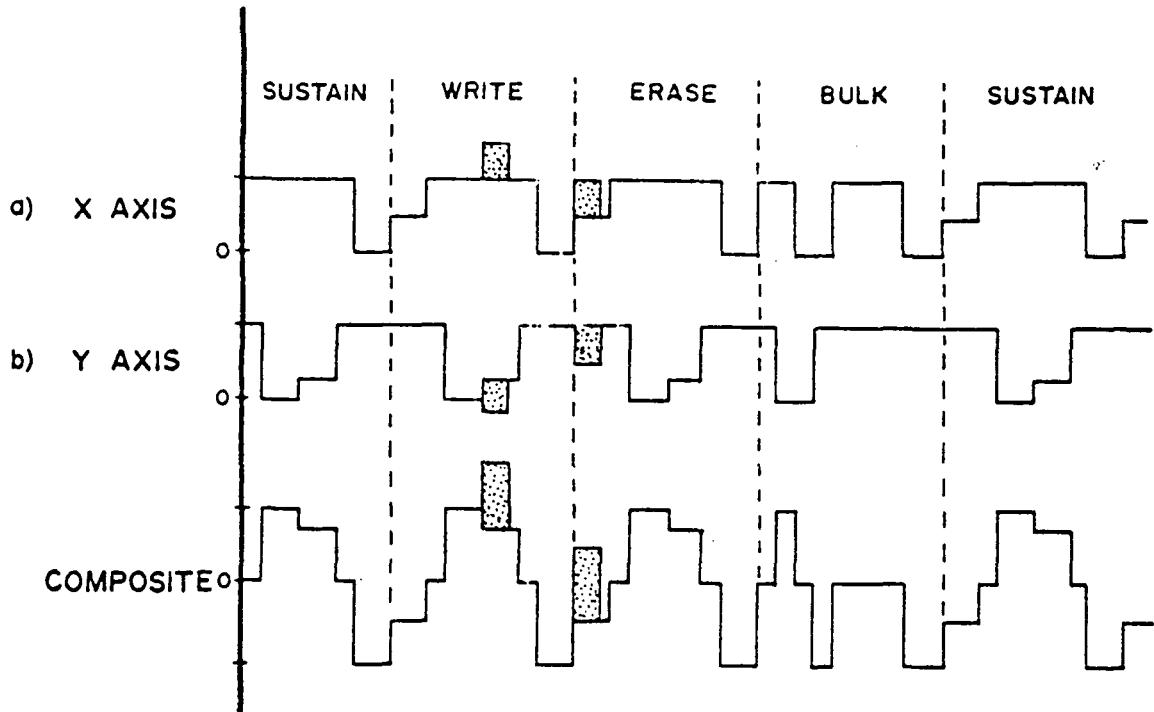
Fig. 3-5. Plasma panel sustainer waveform.

c. Resistor-Pulser Circuit

The resistor-pulser section consists of one strobe circuit and 16 pulser circuits for each side of the panel connected, as shown in Fig. 3-6

The Y axis resistor pulsers are selected by either an address decoder while operating serially or directly through the parallel inputs while in the parallel mode. Logic gating controlled by the mode line enables either of the two methods of selection.

At the appropriate time during the sustainer waveform cycle, the logic produces a pulse of proper duration that simultaneously turns on the strobe transistor and enables the appropriate selector transistor by way of the logic gating. Thus, a current is allowed to flow through the primary coil winding, resulting in the selected resistor pulser(s) being turned on.

The resistor-pulser power supply floats on top of the sustainer waveform. In the case of the Y axis, this supply is negative with respect to the sustainer; therefore, when the resistor pulser is turned on, a pulse that is 100 V (nominal) less

than the voltage of the sustainer waveform appears at its emitter. [In the X axis the selector transistor is an NPN, and the pulser power supply is positive with respect to the sustainer. Therefore, the pulses produced by the X axis resistor pulsers are 100 V (nominal) greater than the voltage of the sustainer waveform. Additionally, the selector transistors are selected directly by a decoder, which is enabled along with the strobe transistors.]

The time at which the pulse produced by the resistor pulser occurs during the sustainer waveform cycle depends upon whether points on the display panel are being written or erased. In either case, the resistor pulser operates in the described manner. The duration of the pulse is determined by the length of the logic pulse which turns on the strobe transistor and enables the selector transistor gating. The pulse amplitude is determined by the voltage on the pulser power supply.

d. Diode-Switch Circuit

The diode-switch section consists of 16 diode-switch circuits for each side of the panel, as shown in Fig. 3-7.

The diode-switch transistor is biased in the on state by the 2-volt power supply in its emitter-base circuit and remains on for the normal sustain cycle. The diode switch is turned off only when writing or erasing one of the points on the display panel with which it is associated.
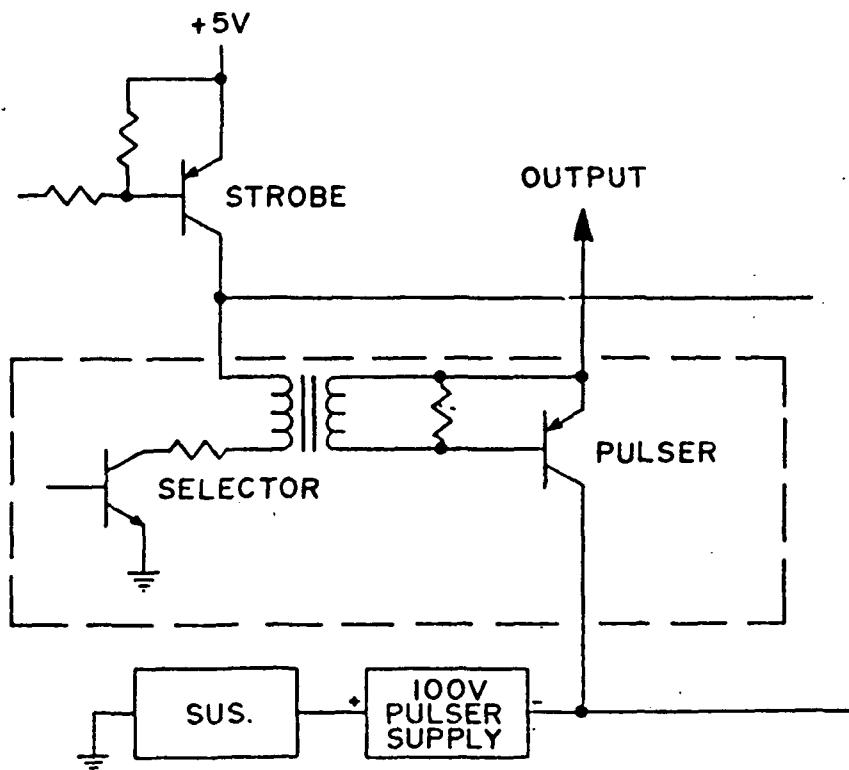


Fig. 3-6. Resistor pulser circuit.

OUTPUT
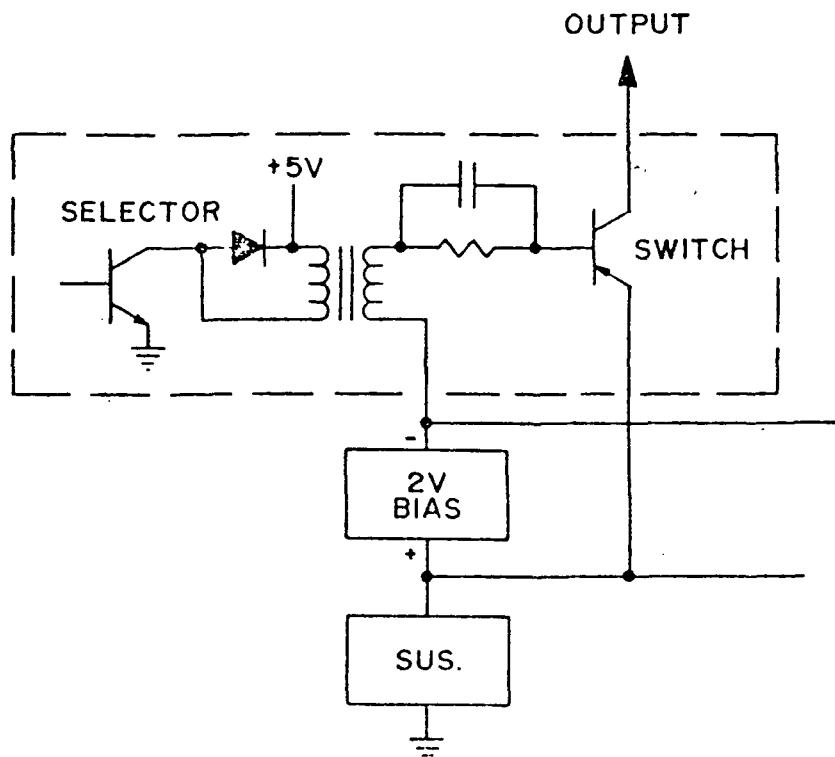


Fig. 3-7. Diode switch circuit.

The Y address logic selects the required diode switch to be turned off by turning on the appropriate selector transistor. (When in either the serial or parallel mode, only one diode switch is selected at one time.) The logic pulse which enables the resistor pulser also enables the Y address logic so that the diode switch is turned off simultaneously with the turning on of the resistor pulser(s).

The 2-volt bias supply floats on top of the sustainer waveform and, in the Y axis, is negative with respect to the sustainer waveform voltage. (In the X axis, the diode switch transistor is an NPN and the 2-volt bias supply is positive with respect to the sustainer.)

e.  Diode-Resistor Matrix

The diode-resistor matrix consists of two diodes and one resistor for each electrode on the panel (Fig. 3-8).

3-45
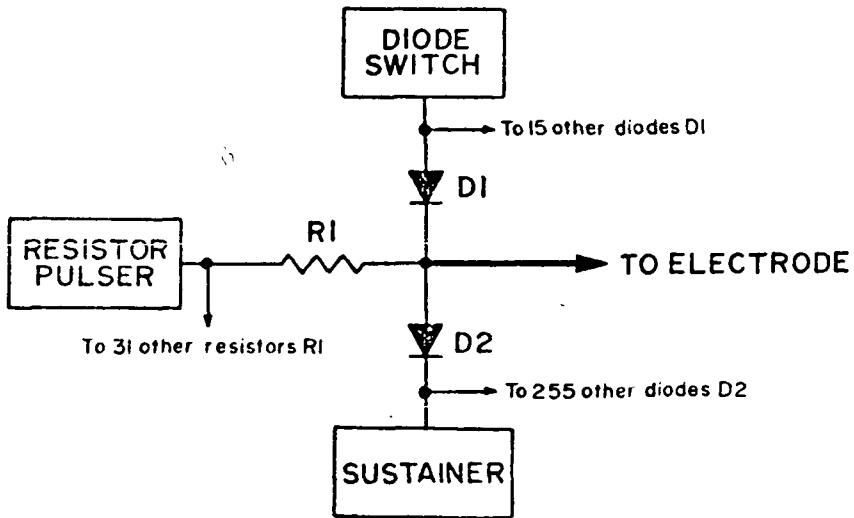
Fig. 3-8. Diode resistor matrix.

All sustainer isolation diodes (D2) associated with the even-numbered display panel Y axis electrodes are bussed together to one sustainer circuit. The odd-numbered electrodes are likewise bussed together to another sustainer circuit. Diode D1 and resistor R1 are used to multiplex the write and erase pulses onto the electrodes of the display panel and are grouped according to Fig. 3-9. Each group of diodes D1 is connected to an individual diode-switch circuit, and each group of resistors R1 is connected to an individual resistor-pulser circuit in such a way that only one electrode will be connected to both the selected resistor pulser and diode switch. Diodes D1 and D2 work in combination to supply sustain currents to each electrode.

During normal sustain operation, i.e., no points are being written or erased, no address pulses are generated by the resistor pulsers and all diode switches are biased on, each point in the display panel "sees" the sustainer waveform and, if it is in the written state, the diode switch associated with it accepts its discharge currents.

When a point on the display panel is to be written, the appropriate diode switch for the Y axis line that intersects the point is turned off and the required resistor pulser is made to produce a pulse. At this time, four conditions exist. First, those electrodes not associated with either the diode switch or resistor pulser which have been selected will receive only the ordinary sustaining waveform. Second, those electrodes associated with only the selected diode switch will also receive only the ordinary sustaining waveform. (The diode switch is turned off only when not required to accept discharge currents.) Third, those electrodes associated with only the selected resistor pulser will again receive only the ordinary sustaining waveform, since the pulse from the resistor pulser is dumped through diode D1 and the nonselected
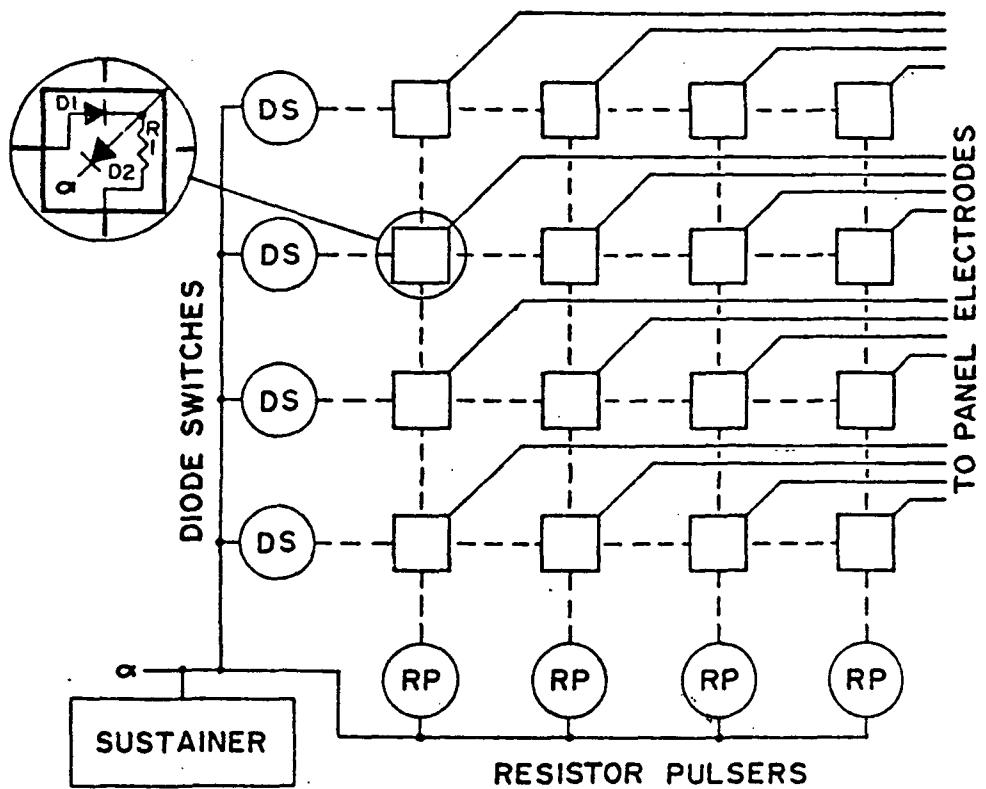
Fig. 3-9. Addressing circuitry.

diode-switch transistors. In this case, the pulse energy is dissipated across resistor R1. Fourth, the electrode which is common to both the selected resistor pulser and diode switch will receive a modified sustainer waveform, as illustrated in Fig. 3-5b. The pulse produced by the resistor pulser will be forced to appear on the electrode since the associated diode-switch transistor has been turned off, causing diode D1 to be reverse biased. (Similar addressing occurs in the X axis, except that the sustainer waveform in the fourth case is illustrated by Fig. 3-5a.)

The point on the display panel which is at the intersection of the selected electrodes in the X and Y axis will "see" the waveform illustrated in Fig. 3-5c. This waveform will result in this point being written. This is the only combination of X and Y axis waveforms which will result in a point being written.

In the parallel mode, a maximum of 16 cells may receive the necessary waveform to cause them to be written, depending upon the number of resistor pulsers being selected.

The erasing of a point in the display panel (or points in the case of parallel addressing) is much the same as the writing operation, and it differs only in the time at which the resistor pulser and diode switch are selected with respect to the timing of the sustainer waveform cycle. The Y axis, X axis, and composite waveforms for the erase operation are illustrated in Fig. 3-5.

3. Address Logic

    a. Y Address

        The Y axis is divided into 32 sectors, each of which contains 16 consecutive electrodes. The sectors are numbered from 0 through 31 and the electrodes in each sector are numbered from 0 through 15. One diode switch is associated with each sector.

        The Y address word consists of 9 bits, i.e., $Y_0$ through $Y_8$. When in the parallel mode, an additional 16 input signals, $P_0$ through $P_{15}$, are required.

        Bits $Y_5$ through $Y_8$ are used to select two of the 32 diode switches in the Y axis, i.e., diode switches 0 & 1, 2 & 3, etc., such that the two diode switches are associated with a 32-consecutive electrode segment of the display panel. Bits $Y_0$ through $Y_3$ are used to select the resistor pulsers which are associated with the upper and lower group of 16 electrodes in each group of 32 electrodes selected by the diode switches. Bit $Y_4$ determines whether the resistor pulsers for the upper or lower group of 16 electrodes will be enabled.

        If the following Y address word is presented while operating in the serial mode,

| $Y_8$ | $Y_7$ | $Y_6$ | $Y_5$ | $Y_4$ | $Y_3$ | $Y_2$ | $Y_1$ | $Y_0$ | |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | |
| 8 | 4 | 2 | 1 | 1 | 8 | 4 | 2 | 1 | Address decoding binary values |
| 256 | 128 | 64 | 32 | 16 | 8 | 4 | 2 | 1 | Pure binary address |

the following selection process takes place. Diode switches 10 and 11, which control electrodes number 159 through 191, are selected by bits $Y_5$ through $Y_8$. Bit $Y_4$ further selects electrodes 175 through 191. Finally, bits $Y_0$ through $Y_3$ select electrode number 181 as the one to receive the pulses necessary to write or erase the point at its intersection with the selected electrode in the X axis.

        If the display unit were to be operating in the parallel mode and the following parallel input signals were to be provided along with the foregoing Y address word,

        $P_0$ through $P_5$ = logical "0"
        $P_6$ through $P_{15}$ = logical "1"

the sequence of selecting the Y electrodes would be changed somewhat. Bits $Y_4$ through $Y_8$ will function as when operating serially so that, again, electrodes 175 through 191 will be selected. Bits $Y_0$ through $Y_3$ will not be used; instead, the parallel inputs will make the final selection as to which electrodes will receive the write or erase pulses. In this case, electrodes 175 through 180 associated with $P_0$ through $P_6$ will not be selected. Electrodes 181 through 191 associated with $P_6$ through $P_{15}$ will be selected so that the points at the intersection of these ten electrodes, with the electrode selected by the X address, will receive the write or erase pulse.

b. <u>X Address</u>

The X address word consists of 9 bits and is used to select only one electrode regardless of the mode of operation in which the display unit is being used. The selection sequence is identical to that of the Y axis serial operation.

4. Parallel/Serial Model Power Supply

a. <u>Input/Output Requirements</u>

<u>Input</u>:

105–125 Vac, 60 Hz

250 Watts (typical) (3-A Slo-Blo fuse)

<u>Outputs</u>:

Sustainer Supply . . . . . . . . 105 to 140 Vdc* @ 750 mA

Border Supply . . . . . . . . . 3 to 80 Vdc* @ 43 mA (when boosted)

Pulser Supplies (2) . . . . . . 36 to 90 Vdc* @ 150 mA (X axis) 1 A (Y axis)

Bias Supplies (2) . . . . . . . . 2 Vdc @ 150 mA

Logic Supply . . . . . . . . . . 4.5 to 5.5 Vdc @ 2 A

Sustainer Bias . . . . . . . . . 4.5 to 5.5 Vdc @ 2 A

*Adjusted to meet requirements for each display unit.

b. Line Voltage Rectifier Section

The incoming line voltage (115 Vac) is filtered by an EMI filter and rectified by a full wave bridge to produce 149 Vdc (unregulated). This voltage, in turn, is supplied to the inputs of the inverter section and smoothed by a capacitor.

A thermistor is incorporated in the circuit to limit the current surge on initial start-up so that approximately 30 seconds are required before the power supply output voltages reach their operating potential.

When the supply is turned off, the line power must be left off for a period of 30 seconds to allow the thermistor to cool. If this is not done, the ac input fuse may open due to excessive current.

c. Inverter Section

The inverter section consists of two printed-circuit cards — inverter #1 (PS 8) and inverter #2 (PS 7). Inverter #1 supplies the unregulated voltages to the sustainer and border regulator boards. Inverter #2 supplies the unregulated voltages to the pulser, bias, and 5-volt regulator boards.

The incoming 149V from the line rectifier section is chopped at a frequency of approximately 25 kHz by two chopper transistors (two for each inverter) and fed to the primary winding of a transformer.

The voltages induced in the various secondary windings of the transformer are rectified by full wave bridges and then supplied to the appropriate regulator circuit.

A unijunction transistor oscillator on each inverter card is used to start the chopper oscillation.

d. Voltage/Current Regulator Section

(1) Sustainer Regulator

The sustainer regulator consists of one printed circuit card (PS 4) and requires 150 Vdc and 25 Vdc for operation (unregulated output voltage and integrated circuit supply voltage, respectively). The sustainer regulator circuit is built around one integrated circuit which senses voltage level and current requirements and drives a coupled Darlington series pass transistor. The output voltage is adjustable from 105 to 140 Vdc by a board mounted potentiometer, and the current is preset at the production facility for 750 mA maximum output. The output voltage is system ground referenced.

Initially when the supply is turned on, the series pass transistors remain turned off until the sustainer bias supply has reached operating voltage, at which time they are automatically turned on. The time from the application of ac power to the turn-on of the sustainer regulator is approximately 15 milliseconds.

Should an over-current condition occur, the sustainer regulator circuit is designed to turn off the series pass transistors completely rather than operate in a normal current-limiting mode. Once the deficiency which caused the excessive current drain has been corrected, it is necessary to interrupt ac power to the power supply for approximately 30 seconds to restart.

### (2) Border Regulator

The border regulator consists of one printed-circuit card (PS 6) and requires 100 Vdc and 25 Vdc for operation (unregulated output voltage and integrated circuit supply voltage, respectively). The circuit configuration is similar to that of the sustainer regulator; however, operation differs somewhat. The regulator IC drives only one series pass transistor and operates in a normal current limiting mode, i.e., does not shut down or require initial starting as does the sustainer regulator circuit.

The primary distinction of the border regulator circuit is that its output is referenced to the sustainer voltage and may be boosted from its quiescent voltage to a higher output level. The quiescent and boost levels are individually adjusted by board mounted potentiometers. The total output range is 3 to 80 Vdc with a preset maximum current capability of 43 mA. The border voltage as supplied to the display unit will be the sum of the sustainer and border regulator output voltages.

The border output voltage is boosted as soon as the sustainer regulator is turned on and remains boosted for approximately 10 seconds, after which time the border voltage drops to its normal operating level.

### (3) Pulser Regulator

The pulser regulator section comprises two identical circuits, both mounted on a single printed-circuit card (PS 2) and requires 100 Vdc and 25 Vdc for operation (unregulated output voltage and integrated circuit supply voltage, respectively).

The regulator circuit consists of an IC which drives a single series pass transistor and associated components for voltage adjustment and current sensing. The circuit operates in a normal current-limiting mode.

The output is adjustable by board mounted potentiometer from 36 to 90 Vdc with a preset current capability of 150 mA (X axis) and 1 A (Y axis). The output is floating and is referenced to the appropriate sustainer waveform at the display unit.

(4)  Bias Regulator

The bias regulator comprises two identical circuits, both mounted on a single printed-circuit card (PS 1) and requires only unregulated 10 Vdc for operation.

The bias regulator circuit is made up of discrete components and is of the series pass transistor type. The output is preset at 2 Vdc (may be adjusted with card mounted potentiometer) and for 150 mA.

The output is floating and is referenced to the appropriate sustainer waveform at the display unit.

(5)  5 V Regulator

The 5 V regulator consists of two identical circuits (5 V logic and 5 V sustainer bias) mounted on one printed-circuit card (PS 3) and requires only unregulated 12 Vdc for operation.

The 5 V regulator circuit utilizes an integrated circuit to drive a single-package Darlington configuration series pass transistor.

The output of the 5 V regulator is adjustable by a board mounted potentiometer from 4.5 to 5.5 Vdc and has a preset current capability of 2 A. The output is referenced to system ground.

In the event that an excessive voltage appears at the output, an SCR is automatically turned on which shorts the incoming unregulated 12 Vdc to ground, thereby opening a board mounted fuse which is in series with the 12 Vdc. This is done to prevent the unregulated 12 Vdc from being supplied to the logic in the event that the over-voltage condition should cause the series pass transistors to short or the regulator integrated circuit to fail.

5.  Plasma Panel Adjustment

The operating voltage levels applied to the plasma panel are developed by the plasma panel power supply which is mounted immediately below the panel. These voltages have been adjusted for optimum performance. If due to aging the panel should double write or fail to write in an addressed position, improved performance may be obtainable by adjusting the sustainer and X and Y pulser voltages. These adjustments are made in the power supply unit by vaning pots located on the printed circuit board facing the rear of the unit. Pots which control these voltages are positioned

as shown in Fig. 3-10. The voltages indicated in the figure are the normal operating voltages for the panel supplied with the unit. The X and Y bias voltage on the sustainer current setting should not be changed without consulting RCA or Owens-Illinois. The voltages may be adjusted while in the rack. When doing this however <u>care should be taken to avoid coming in contact with the back ring of brightness control autotransformer. This ring can be as high as 115 volts ac above ground.</u>

## D. HOLOGRAPHIC PROJECTION SUBSYSTEM

Figures 3-11 and 3-12 are schematic representations of the optical system used to project image information from the holographic storage plane to the viewing screen. Figures 3-13 and 3-14 are photographs showing this system as it is assembled in the Multifunction Display Equipment. Table 3-12 lists the characteristics of this system.

The optical system is assembled on a pull-out drawer located at the top of the unit behind the viewing screen. The complete optical system required for the reconstruction of the stored image information as well as the tape transport mechanism and the registration optics are contained on this drawer. In order to pull the drawer out it is necessary to remove the four air hoses which duct air into various portions of the optical system and a locking bolt located below the supporting tray at the rear of the equipment. To operate the projection source when the drawer is pulled out, the back of the source housing should be removed and air should be ducted into the assembly using the attached squirrel cage fan.
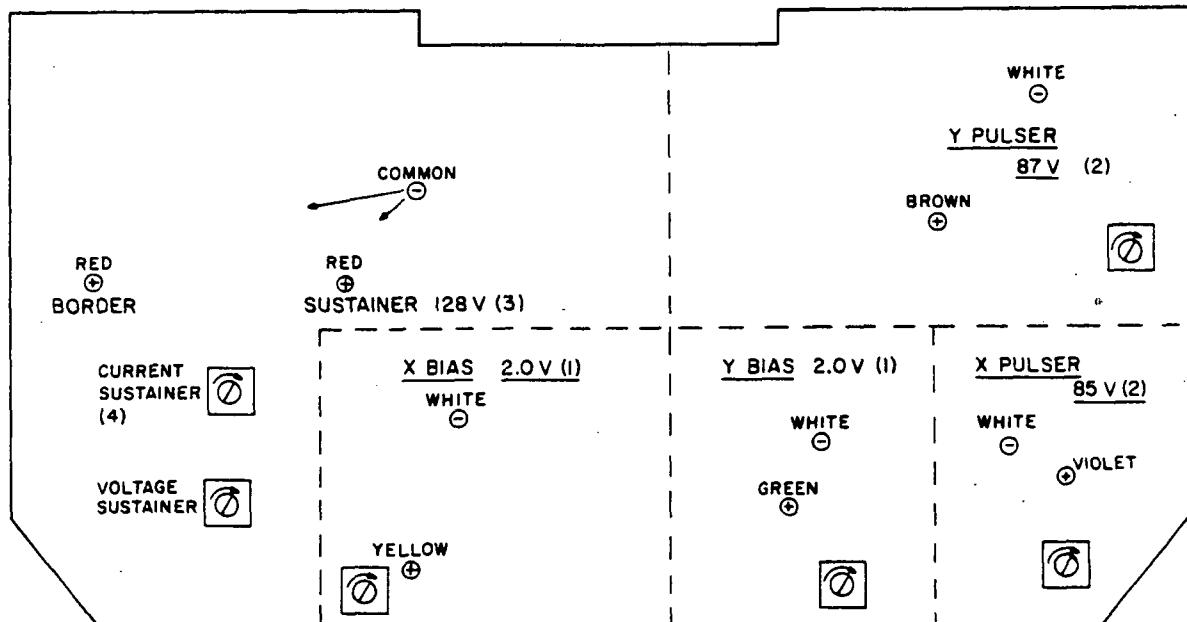


(1) DO NOT VARY
(2) SHOULD NOT BE RAISED ABOVE 92 VOLTS
(3) NO LIMIT
(4) SHOULD NOT BE VARIED

Fig. 3-10. Nominal plasma panel supply voltages.

OPTICAL SOURCE

FOLDING MIRROR

BEAM FORMING LENS FILTER COMBINATION

PROJECTION LENS

FOLDING MIRROR

FOLDING MIRROR

FOLDING MIRROR

PLASMA PANEL

CONDENSER LENS PAIR

LENTICULAR SCREEN
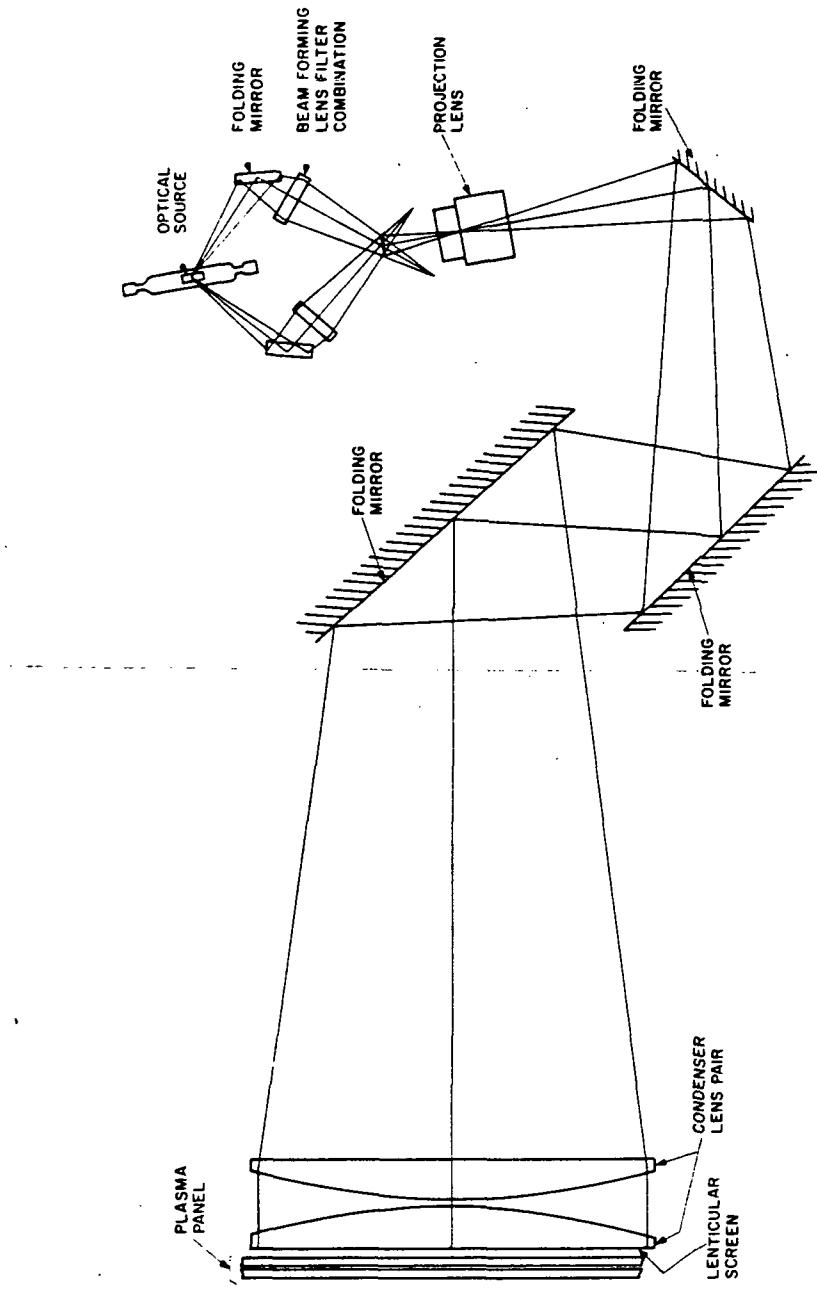
Fig. 3-11. Optical projection system, schematic diagram.
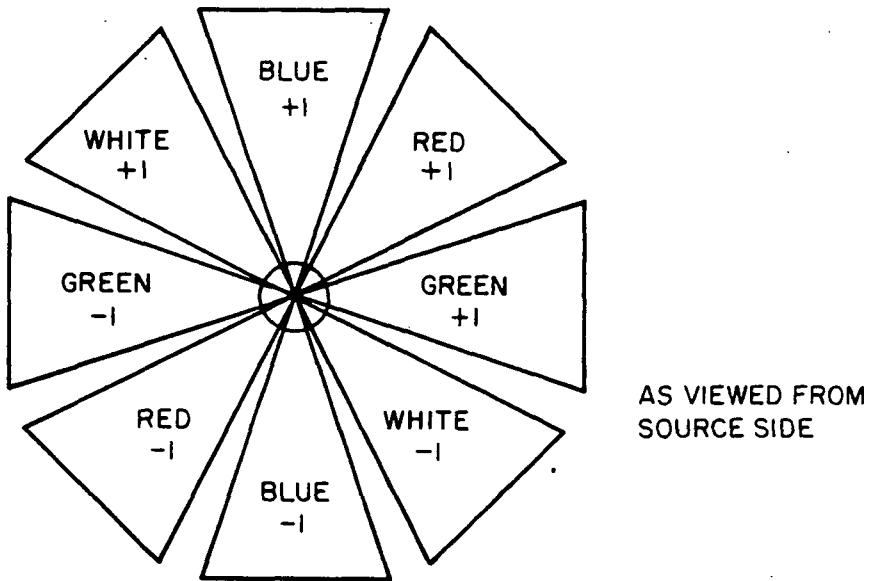
Fig. 3-12. Optical projection system, source configuration.

The air should not be ducted directly over the lamp, but toward the aluminum block containing the registration sensor array. This array is located on the top right of the housing as it is viewed from the rear.

Section IV describes the focused image holographic recording process used for the storage of multicolor information and the method of embossing the recorded information on storage tapes. The function of the optical system of Fig. 3-13 and 3-14 is to interrogate the recorded information. The projection optical chain performing this function consists of a white light (tungsten filament) projection source, eight parallel collection and reference beam forming lenses, filters and folding mirror combinations, the holographic tape strip and imaging lens, folding mirrors and a directional viewing screen.

As indicated in Section IVB, multicolor information is recorded as a superposition of three holograms each of which is used to record one element of a three-element (red, blue and green) color separation set.

The separation set is derived from the original source material by either a photographic or color separation scanning process. The holographic recording process is performed in the image plane of an optical system. A conical reference beam is employed. Readout is accomplished using multiple conical reconstruction wavefronts to interrogate the stored information as shown in Fig. 3-11.
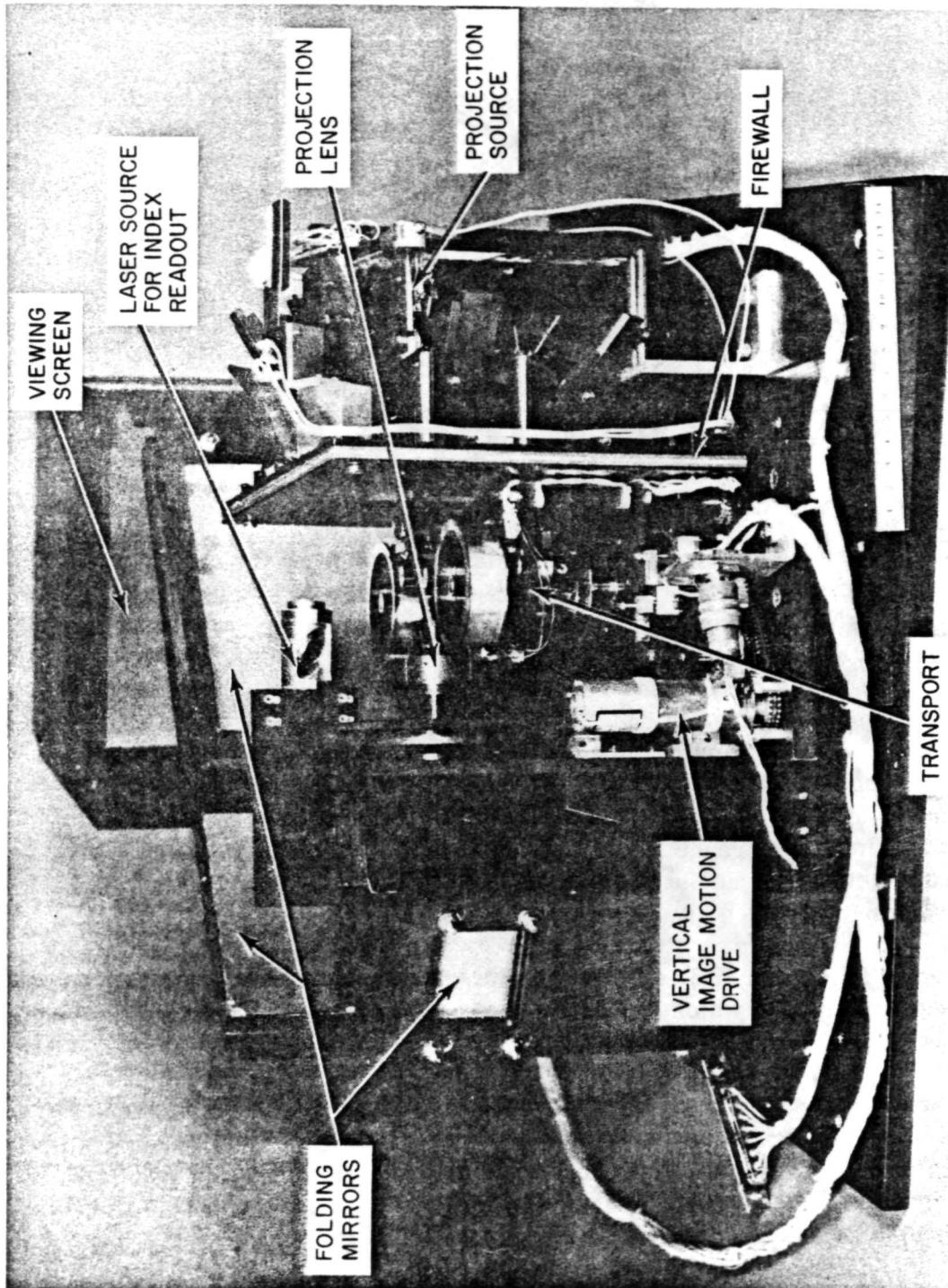
**Fig. 3-13. Optical projection system.**

This page is reproduced at the back of the report by a different reproduction method to provide better detail.
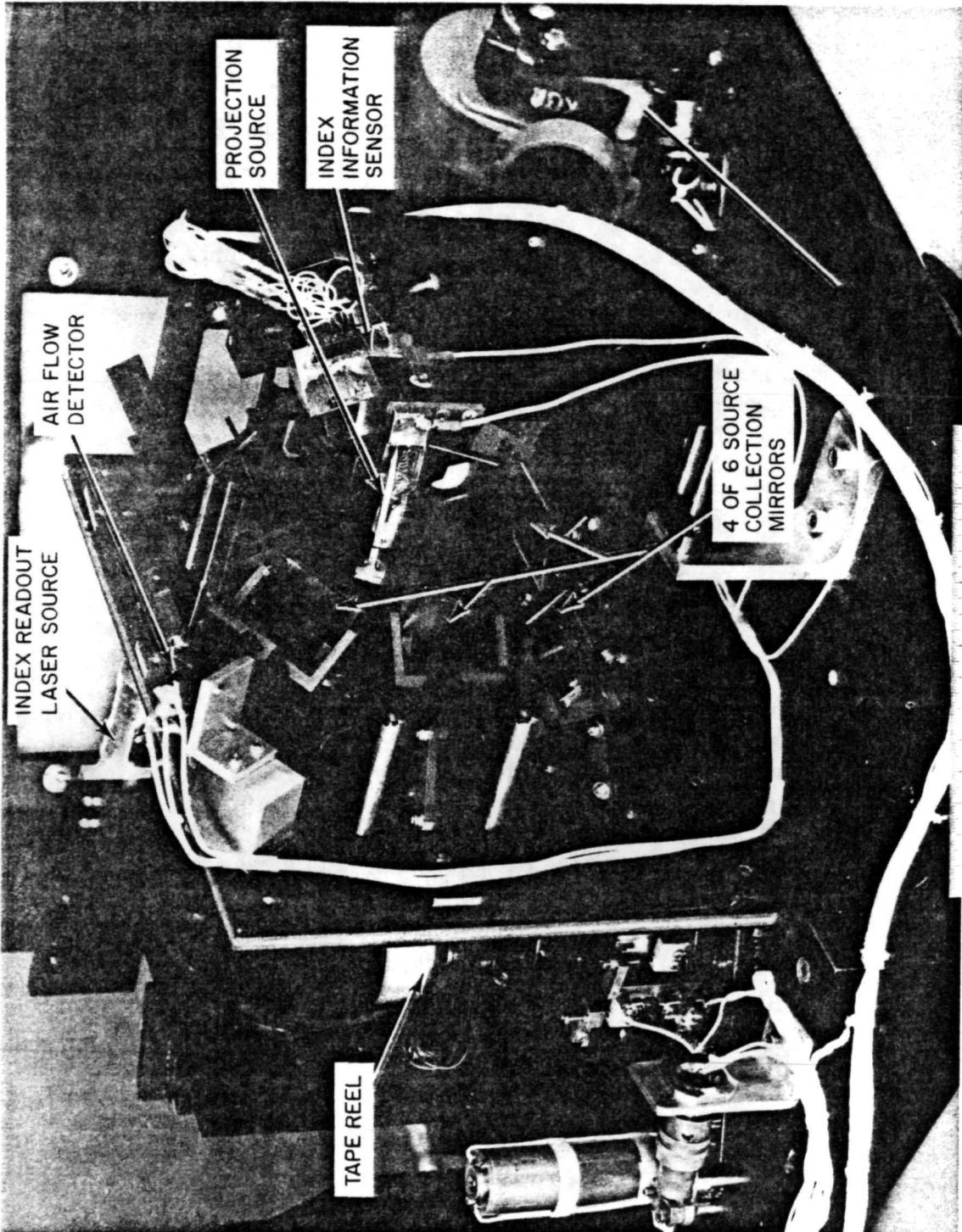
Fig. 3-14. Optical projection system.

Labels on figure:
- PROJECTION SOURCE
- INDEX INFORMATION SENSOR
- AIR FLOW DETECTOR
- INDEX READOUT LASER SOURCE
- 4 OF 6 SOURCE COLLECTION MIRRORS
- TAPE REEL

This page is reproduced at the back of the report by a different reproduction method to provide better detail.

Image information occupying an 8-1/2 inch x 8-1/2 inch area is stored at an 18:1 reduction as a 12-mm x 12-mm hologram. Readout is accomplished by directing readout beams similar to the reference beams used for recording through the hologram. A portion of the energy contained in the readout beam is diffracted by the grating structure of the hologram down the optical axis of the imaging lens system. The diffracted energy is processed (focused) by the lens to form an image of the stored information.

Six reference beams are used simultaneously to interrogate the three superimposed holograms. Folding mirror-collection lens combinations are oriented about the source filament as shown in Fig. 3-12. Each lens operating over an f/4 collection cone collects approximately 3% of the energy radiated by the source. The collected energy is focused to a conical wavefront by the collection lens forming an image of the filament on the same side and at the same distance from the holographic tape as the axial distance to the principal plane of the imaging lens.

A filter is included in each of the optical paths to produce red, blue and green reference beams which are directed through the tape at the proper orientation to read out the superimposed red, blue and green holograms. Two beams are used to read out each hologram. The double beam readout system provides + and - one-order reference beams both of which have diffracted energy components which are directed down the optical axis. The double reference beam system is used for two reasons, first it increases the amount of energy collected from the source and hence the optical efficiency, and second, illumination of the hologram from both sides of the tape provides a method of uniformly illuminating the hologram to provide an image of uniform brightness.

In addition to the six reference beams used to read the multiple holograms, there are two additional readout reference beam paths which are used for the reconstruction of black and white information. Black and white information is recorded at a fourth grating angle with respect to the three color separation holograms. The folding and collection optics used for this path is the same as that used for the construction of the red, blue and green readout beams with the exception that in this case there is no filter included in the optical path.

Black and white information can be reconstructed using the red, blue and green reference beams and the same restoration process used to restore color information. However, the use of a fourth restoration channel (two complementary unfiltered readout beams) eliminates the requirement for producing a three-element separation set from black and white source material and the performance of a registered recording process as is required for the recording of color information, resulting in a significant simplification of the recording process for black and white information.

## 1. Imaging Process

Energy is diffracted from the readout beams (6 for color restoration, 2 red, 2 blue, 2 green or 2 for black and white information) as the readout beams are transmitted through the storage holograms. The hologram is a phase hologram which captures the interference pattern formed during the recording process (see Section IV) as a complex diffraction grating stored as a surface distortion of the storage medium. The phase characteristics of the reference beam are distorted by the difference in path length of the beams in the storage material produced as a result of the surface distortion. The distortion in the phase characteristics of the optical wavefront results in the diffraction of energy toward the imaging lens of Fig. 3-11.

The use of overlayed holograms, one for red, a second for blue and a third for green (a hologram oriented for readout by the white readout beam is not generally used when full color information is read out) along with properly oriented paired red, blue and green reference beams cause the diffraction of energy from the red readout beam as it is interrogated by the red hologram to be directed toward a readout imaging lens. Although the holograms associated with the green and blue information also diffract energy from the red beam, the energy diffracted by these holograms does not fall in the aperture of the readout lens and, hence, is not imaged to the viewing screen. A similar condition exists for the blue and green readout channels.

The fact that the information is recorded as a focused image hologram allows the restoration to be accomplished using a conventional imaging lens. The lens used in the delivered equipment is an f/1.2, 32-mm lens, stopped down to f/3.0. As the intercepted diffracted energy is focused to an image plane by this restoration lens, the imaging process is accomplished with 18:1 magnification to produce 3-1/2 inch x 8-1/2-inch image from the 12-mm x 12-mm multiple focused image holograms. Using a 400-watt source, an image is produced which has a 10-lp/mm resolution at a 40% response, and which if viewed on a lossless diffuse viewing screen would have a brightness of approximately 15 footlamberts.

## 2. Viewing Screen

In order to provide a display that can be acceptably viewed in a high ambient environment and which can also be integrated with the plasma panel of Section IIIC, a directional viewing screen is incorporated in the image plane as indicated in Fig. 3-11. The viewing screen is located immediately in back of the plasma panel. It is mounted on the optical assembly drawers and can be removed with the remainder of the projection optics.

The rear projection of holographically stored information is possible through the plasma panel since it is a transparent device with only a small percent of the active area of the panel masked by the gold electrode structure of the panel.

The directional viewing screen consists of a set of condenser lenses and a lenticular dispersion screen. Two 30-inch condenser lenses are used in a back to back configuration as indicated in Fig. 3-15. Each lens has a focal length of 30 inches and consequently concentrates the energy passing through the 8-1/2-inch x 8-1/2-inch image to a small eye relief area. If the point of energy concentration were viewed without further modification to the viewing system, the display would be extremely bright, but if the head were moved slightly, the collected energy would no longer strike the pupil of the observer's eye; the image could not be seen. The addition of the controlled diffuser screen produces a spread of the energy collected by the viewing screen over a circular eye relief area 1 ft in diameter.

The lenticular screen consists of a piece of plate glass with a series of spherical indentations which are less than 1/250th of an inch in diameter. The indentations are random and act as small negative lenses which spread the concentration of energy produced by the condenser pair over a 1-ft circular eye relief area. This mechanism is shown in Fig. 3-16.

A series of three folding mirrors are located between the reconstruction lens and the viewing screen to fold the optical path so that it is contained within the dimensions of the path.
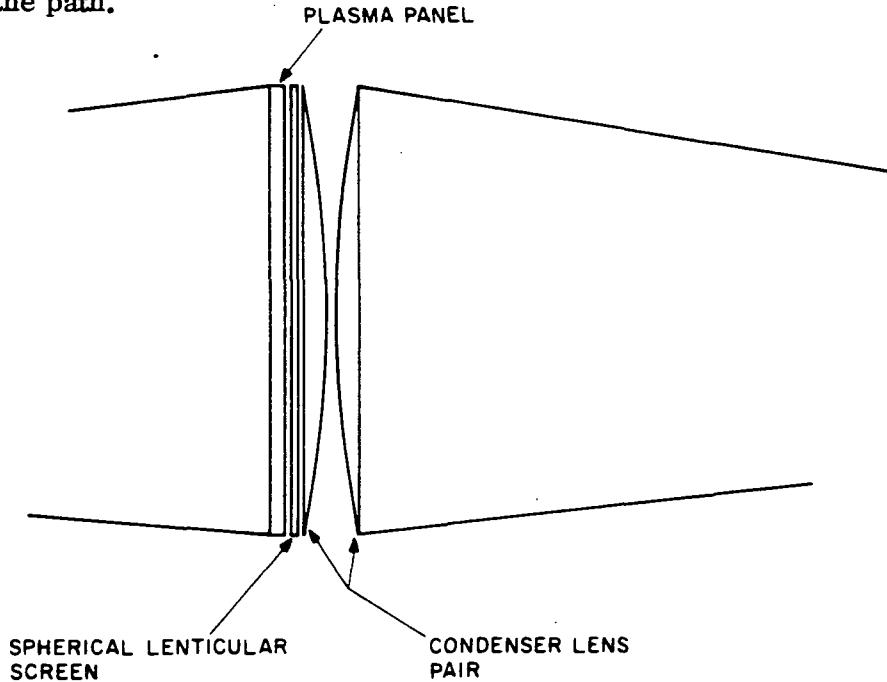


Fig. 3-15. Viewing screen configuration.

CONDENSER PAIR

PROJECTION LENS

(a) WITHOUT LENTICULAR SCREEN

EYE RELIEF AREA

LENTICULAR SCREEN

(b) WITH LENTICULAR SCREEN

ACTION OF LENTICULAR
SCREEN ON A COLLIMATED
WAVEFRONT
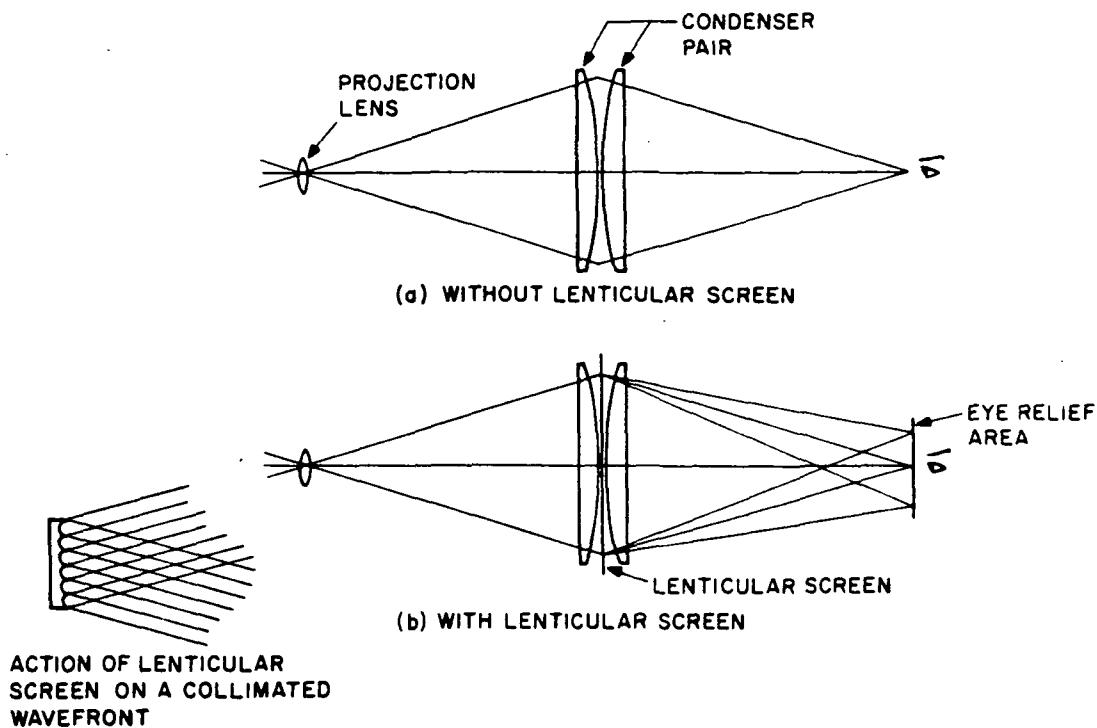
Fig. 3-16. Viewing screen principle.

## E. TRANSPORT CONTROL SYSTEM

### 1. Indexing System

The function of this system is to provide the information necessary for the controlling of the film motion from one location to another. This is accomplished through three system elements working together.

(1) GaAs laser diode source

(2) Fraunhofer Hologram (embossed on the tape strip)

(3) address detectors and buffers.

### a. GaAs Laser Diode Source

The GaAs source is used to illuminate the Fraunhofer hologram. Because this source is collimated and operating at 9040Å, it is not visible to the human eye and care should be taken not to view the output of the source directly. It is positioned as shown in Fig. 3-13. The source driver consists of an oscillator operating at approximately 2 kHz and a capacitor charge and discharging circuit. (See Fig. 3-17.)
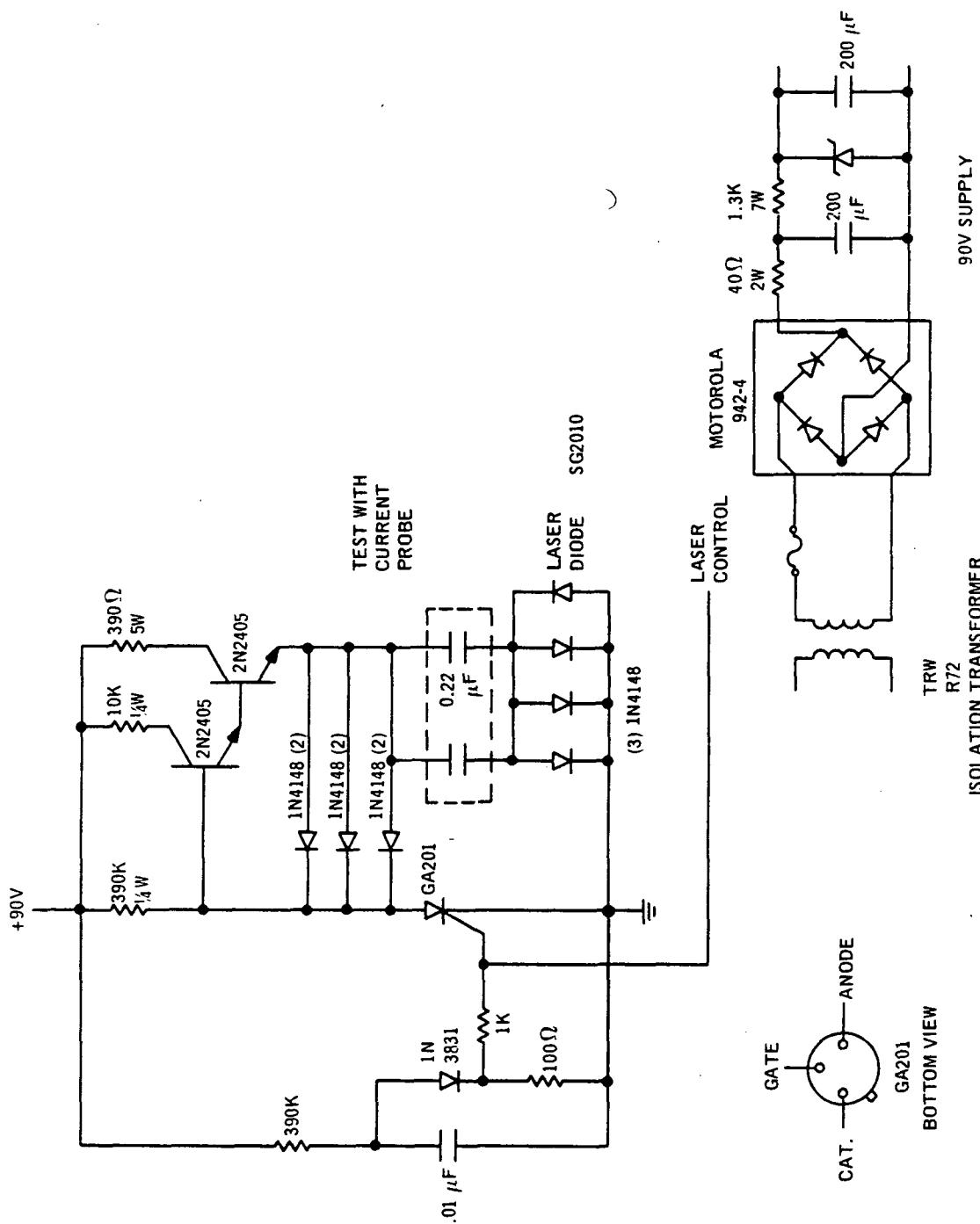
Fig. 3-17.  Laser driver.

The oscillator is formed by the four layer diode (IN3831) and the 0.01 -μF capacitor and 75K resistor. The output appearing across the 100-ohm resistor is used to fire the SCR (GA201). Firing of the SCR dumps the energy stored in the 0.147-μF capacitor through the laser diode, causing the diode to lase. When the SCR turns off, due to insufficient current, the 2N2484 and 2N2405 transistors are used to charge the 0.147-μF capacitor.

### b. Fraunhofer Hologram

As stated earlier, a fifth hologram, a Fraunhofer hologram, is recorded over the image storage holograms. The hologram contains a 5-bit binary code which is used to designate the frame number as well as two auxiliary bits which define when the Fraunhofer hologram is in position to be read out.

The Fraunhofer hologram is read out using the GaAs source previously described and the reconstructed image is positioned to fall into a 7-bit photo transition array. A property of the Fraunhofer hologram is that the reconstructed image is insensitive to the hologram position as long as the hologram is illuminated. Thus, as the film moves, the image remains stationary on the detectors and fades in and out as different frames go through the film gate.

Since the holograms do fade, it is desirable that some means be employed which assures the validity of the data being read. This is accomplished through the signal channels indicated as sync. These two bits are recorded as part of the Fraunhofer hologram, but are shaded in such a way that they fade in after binary information is present and out before the information is lost.

### c. Address Detectors

Figure 3-18 is a schematic of the detector and decoding logic. The schematic shows seven data detectors and two sync detectors in the system. However, only five of the data detectors (20 through 24) are actually wired into the system, the others are furnished so that the unit might be easily expanded at a later date.

The output of the detectors is capacitive coupled and buffered by the 2N5555 FET and the 2N914 transistors. Notice that the sync information is fed to a one-shot whose output is then used to gate the information into the LATCH CIRCUITS (7475). The function of the latch is to hold the previously read information during the period the laser diode source is not lasing. The output of the latch circuit is fed to the Motor Drive Logic.

## 2. Motor Drive Logic

The function of the motor drive logic is to compare two binary words and generate control signals for the motor drive circuitry. This logic is presented in Fig. 3-19. The first word designated by the F scripts ($F^0$-$F^8$) represents the location of the frame being viewed as defined by the indexing system. The second word ($2^X$) represents the location of the frame to be retrieved. This second word is generated from the data word $D^0$-$D^8$ which is received from the computer. This data word is strobed into the latch circuits 2, 25, 11 and 15 by a pulse from the computer (LOAD out). The output of the latch circuits is the desired frame and is designated $2^X$ ($2^0$-$2^8$). The weighting of these bits is as follows: $D^0$ + $D^0$ have a weight of 1, the same as $2^0$, while $F^8$ + $D^8$ have a weight of 256.

The actual comparing is done by $2^{10}$ + $2^4$ and the results are labeled $F<2^X$, $F = 2^X$ and $F > 2^X$. A one on the $F<2^X$ indicates that the desired frame is greater than the present frame and thus is used to drive the transport forward (tape moves from supply reel to takeup reel) while an $F = 2^X$ indicates that we are at the desired frame.

The response curve indicates that it is necessary to slow the transport down one frame before the desired frame. Thus, $Z^1$, 2 and 7 add or subtract one to the desired frame word $2^X$ and produce an outage labeled ($2^X \pm 1$).

This word represents the slow down frame location and is now compared to the present frame F by $Z^3$ and 9. The outputs $F<2^X \pm 1$, $F = 2^X \pm 1$ and $F \ 2^X \pm 1$ give the motor drive logic indications how fast it should be traveling. For example, if $F < 2^X$ and $F < 2^X \pm 1$ then the transport should travel in a fast forward direction, but if $F<2^X$ and $F \not< 2^X + 1$ the transport travels in a slow forward direction. The combining of these signals is done by $Z^3$ on Bd. 8. The other logic on this board is used to combine additional signals and obtain control functions.

On Board 10, Z-9, 16, 10, 17, 11, 18, 12, 19 are comparators used as a read only memory. One side of the comparator has hard wired data information representative of the allowable frame numbers for this system. The other side accepts the desired frame information. For example if the desired frame were 10, then $Z^{11}$ and $Z^{12}$ outputs would be high and $Z^{2-6}$ output would be low while $Z^{3-11}$ is high. Note that this line is also labeled $D^9$ and is a data line seen by the computer. If $D^9$ is forced low, it tells the computer that we reject its request for a particular frame.

## 3. Motor Drive Circuitry

A block diagram of the motor drive circuitry is shown in Fig. 3-20. Circuit diagrams are included in Fig. 3-21. The motor speed is served by comparing
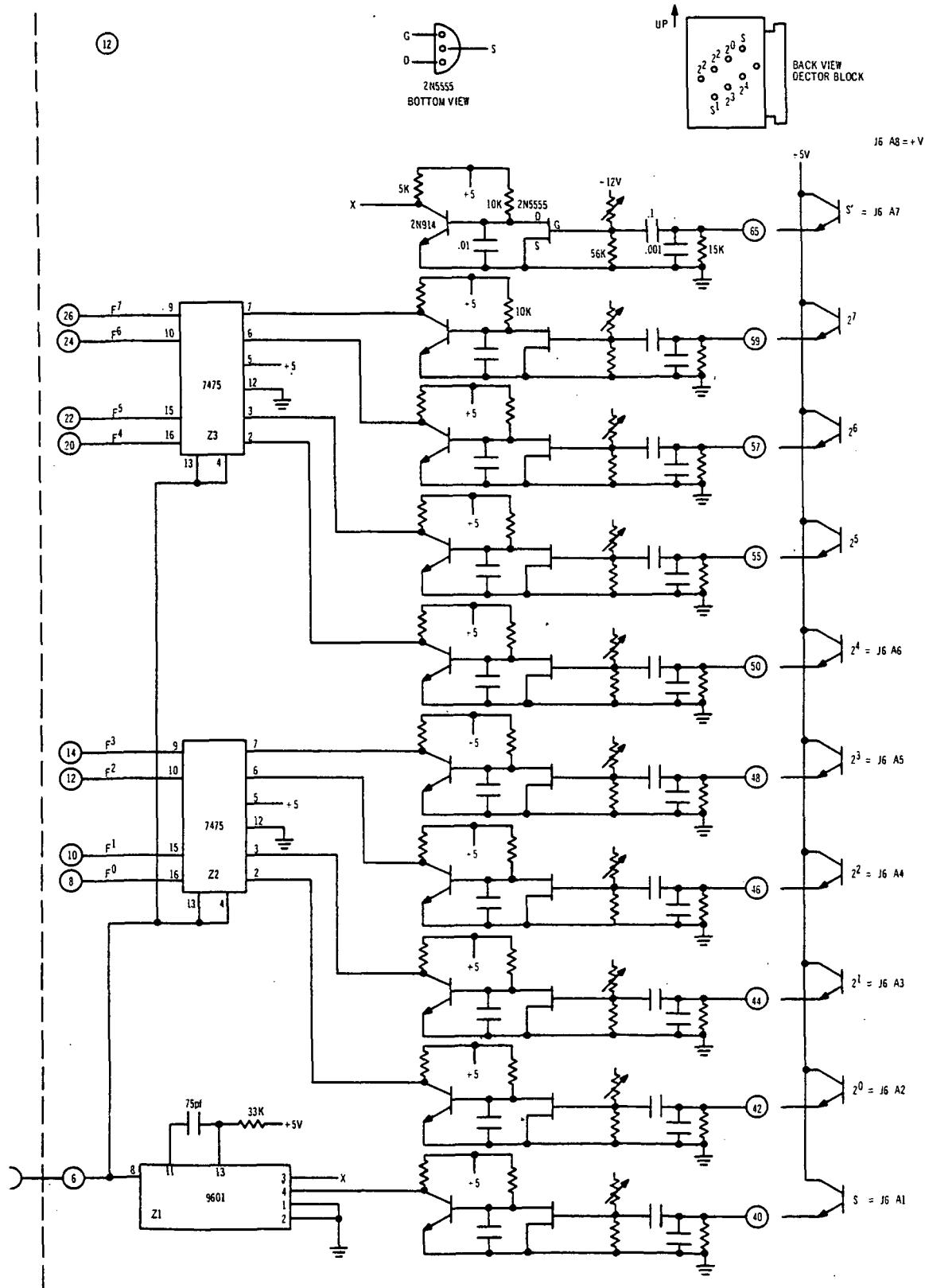
Fig. 3-18. Detection and decoding logic.
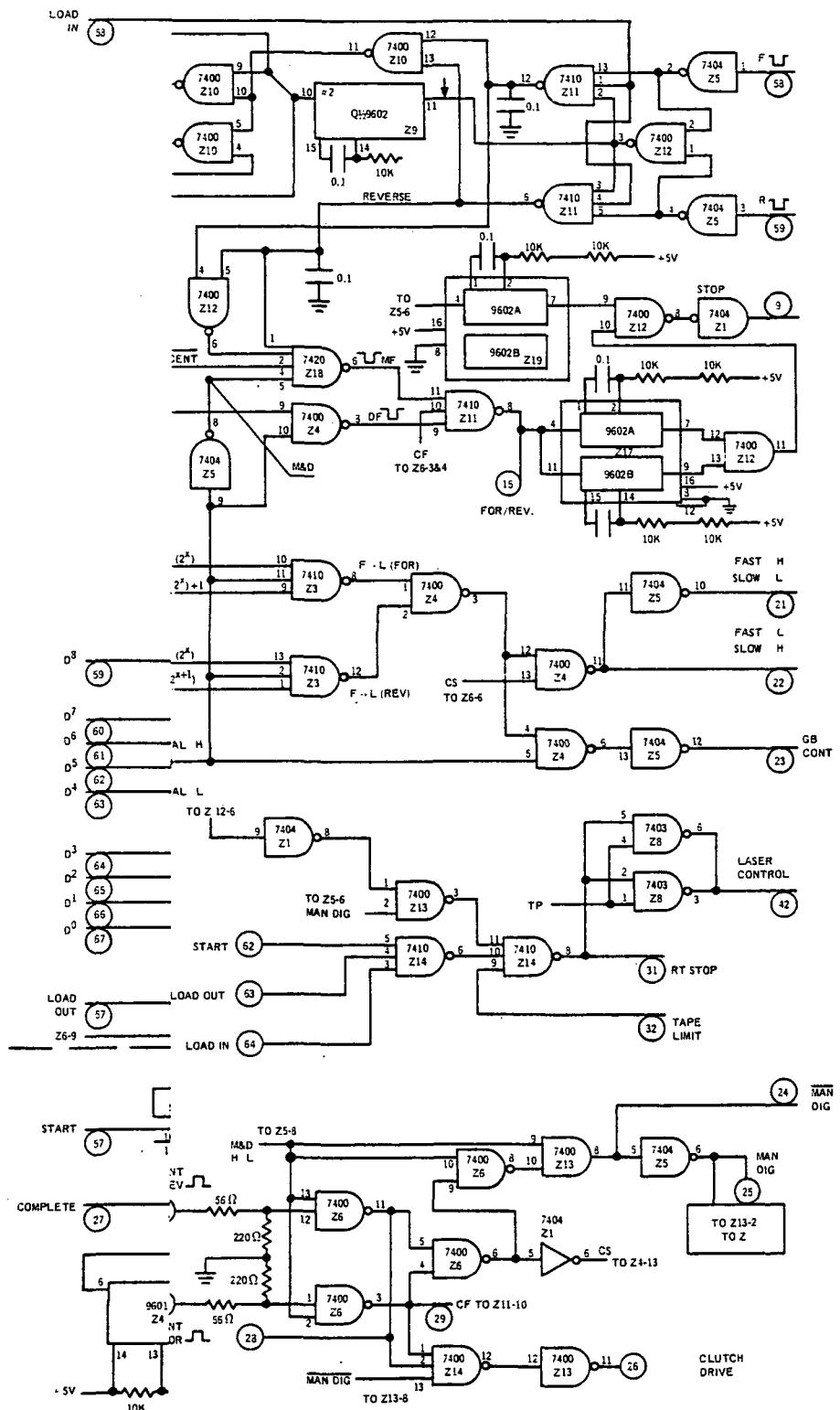
Fig. 3-19. Motor drive logic.

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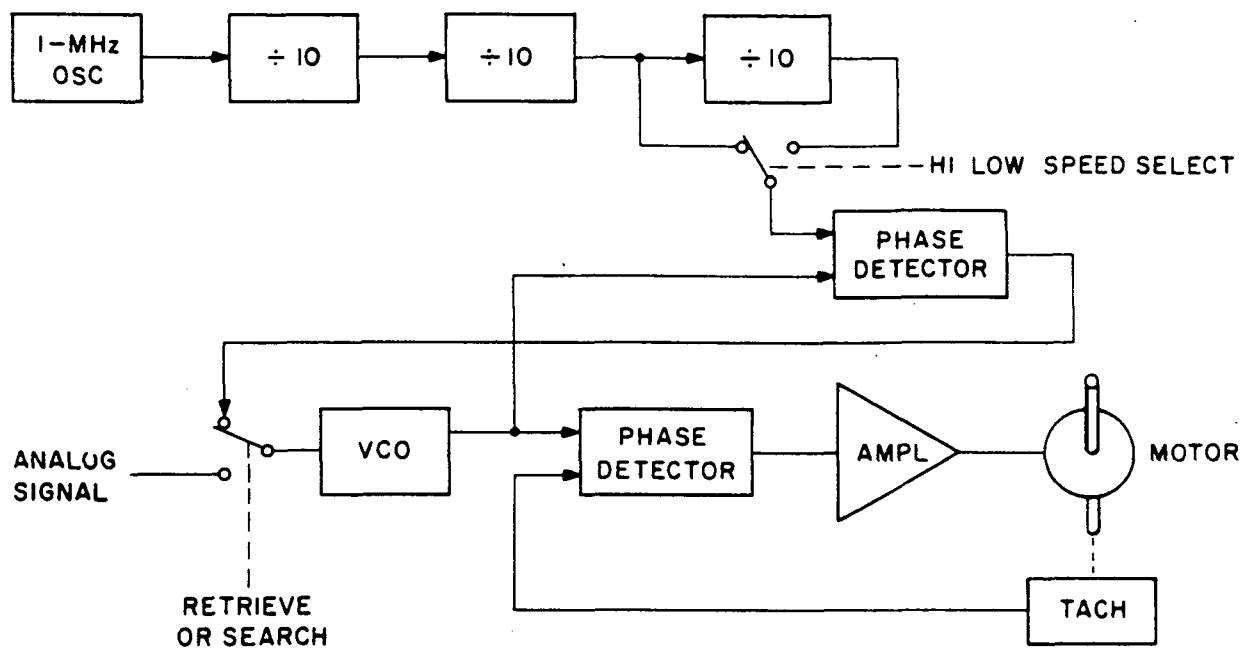
Fig. 3-20. Motor drive, block diagram

a crystal reference to the tachometer output. In the digital mode, the reference is derived from a voltage controlled oscillator (VCO) and is phased back to the crystal reference. When the tape is slowed from a retrieve speed of 1300 mm/s to a stopping speed of 13 mm/s, the VCO output is ramped down to a level corresponding to the lower tape speed.

The motor driver consists of a two-stage preamplifier followed by a complementary-symmetry bidirectional power amplifier. This circuitry is shown in Fig. 3-21 sheets 3 and 4 and in board 4 and the outrigger assembly of the electronics nest. This type of drive enables the motor to be at a standstill when reversing occurs. This technique also prevents any sudden strain from being applied to the tape. The crystal reference source in Fig. 3-21 sheet 1 consists of a 710 with a crystal in the feedback loop.

The divide circuitry is accomplished through the divide by 10 counters, U2 to U4. Located also on this board is one of the phase detectors. This is made up of three chips, U7 to U9, and is the detector previously mentioned that locks the VCO to the crystal reference. The 9602 one-shots are used to provide sharp square pulses for the phase detectors.
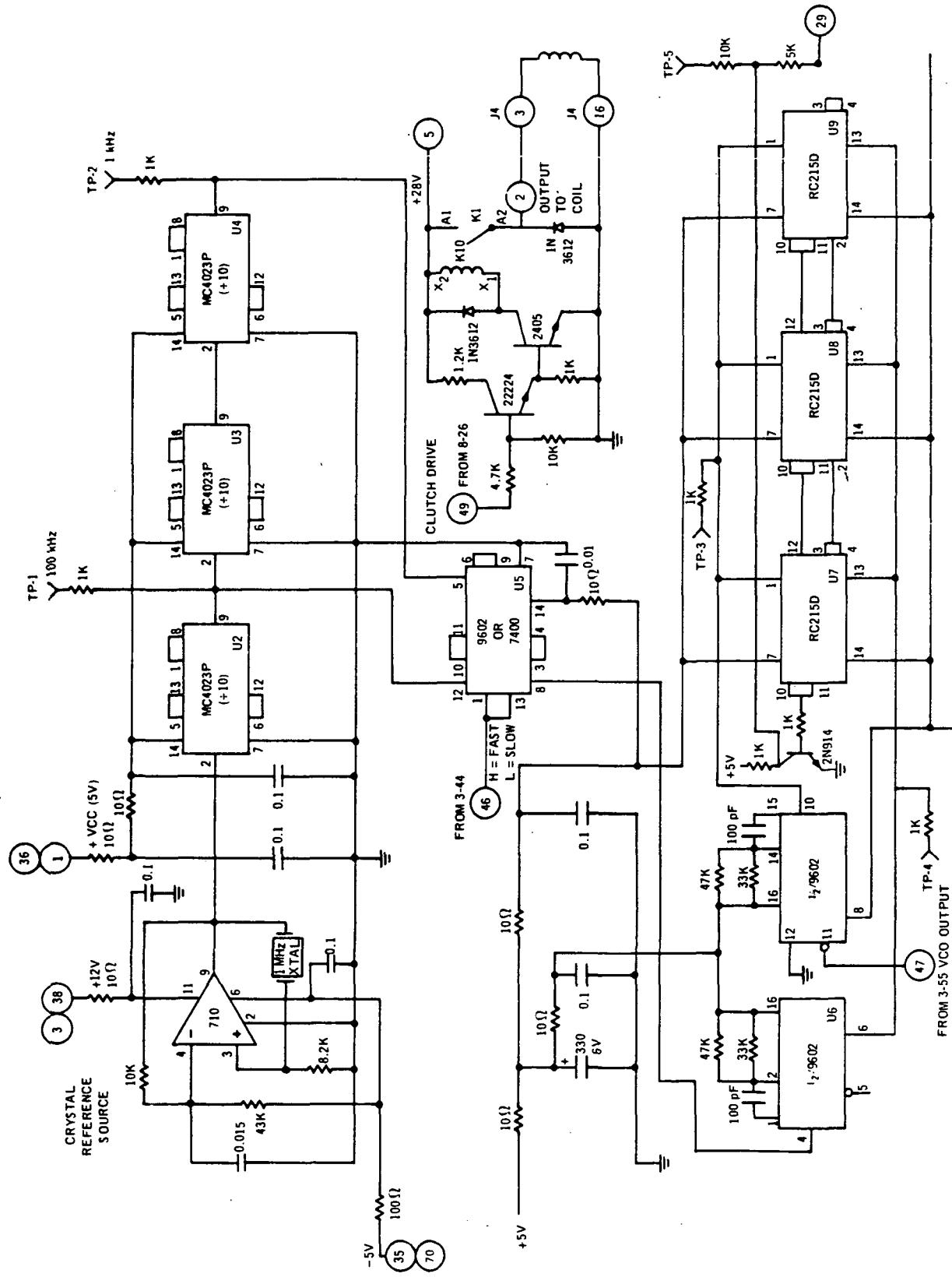
Fig. 3-21. Motor drive, schematic diagram (sheet 1 of 5).
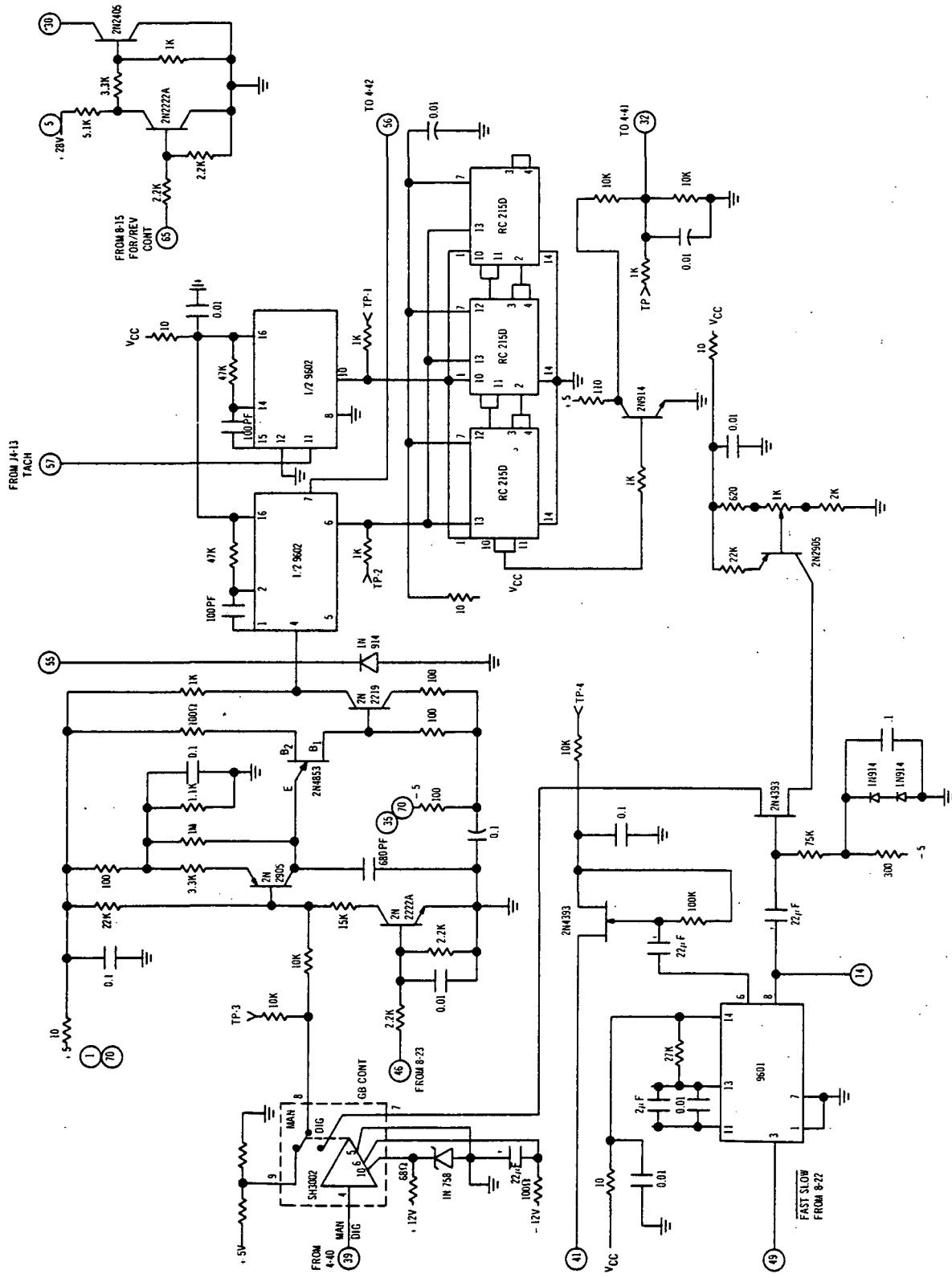
Fig. 3-21. Motor drive, schematic diagram (sheet 2 of 5).
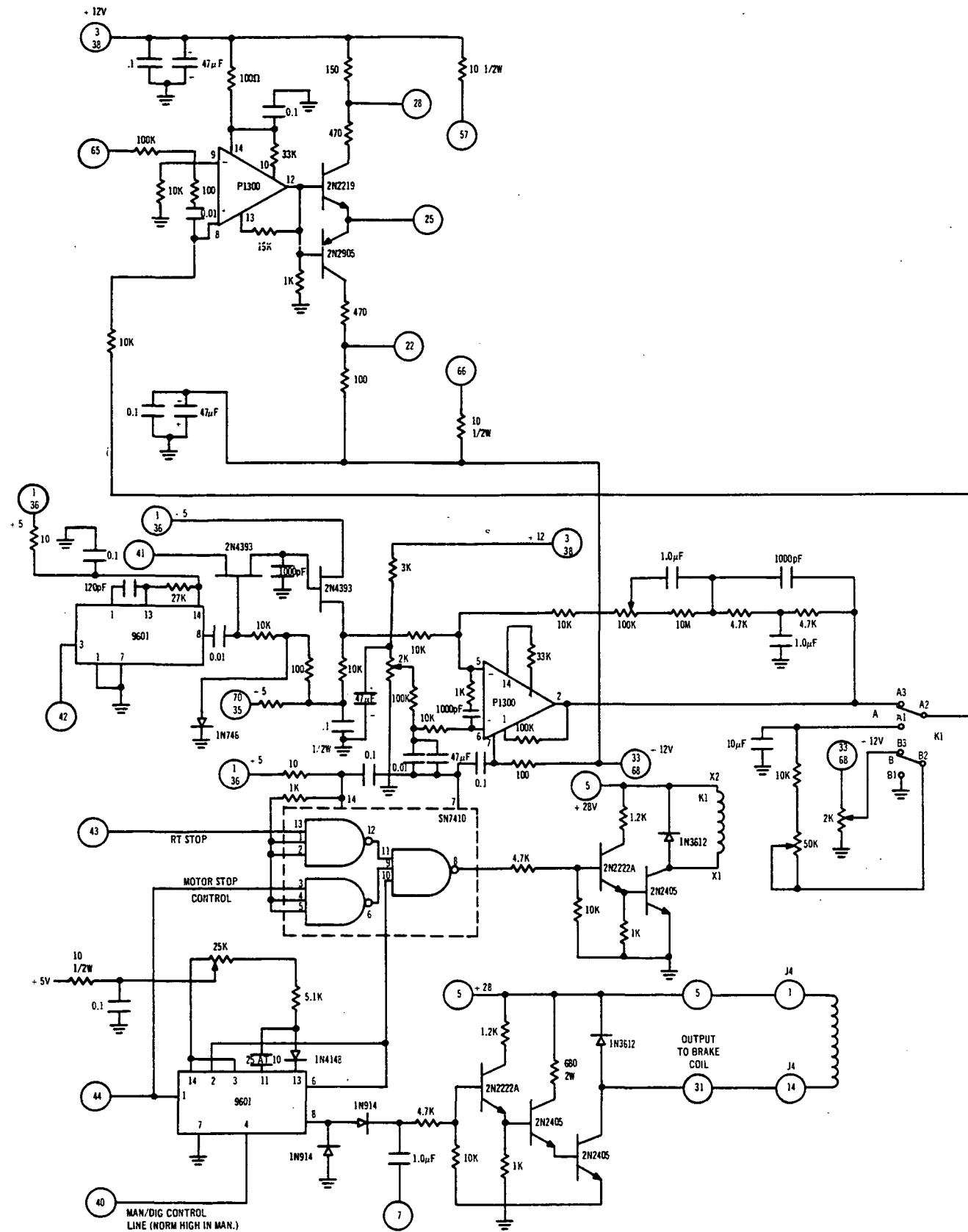
Fig. 3-21. Motor drive, schematic diagram (sheet 3 of 5).
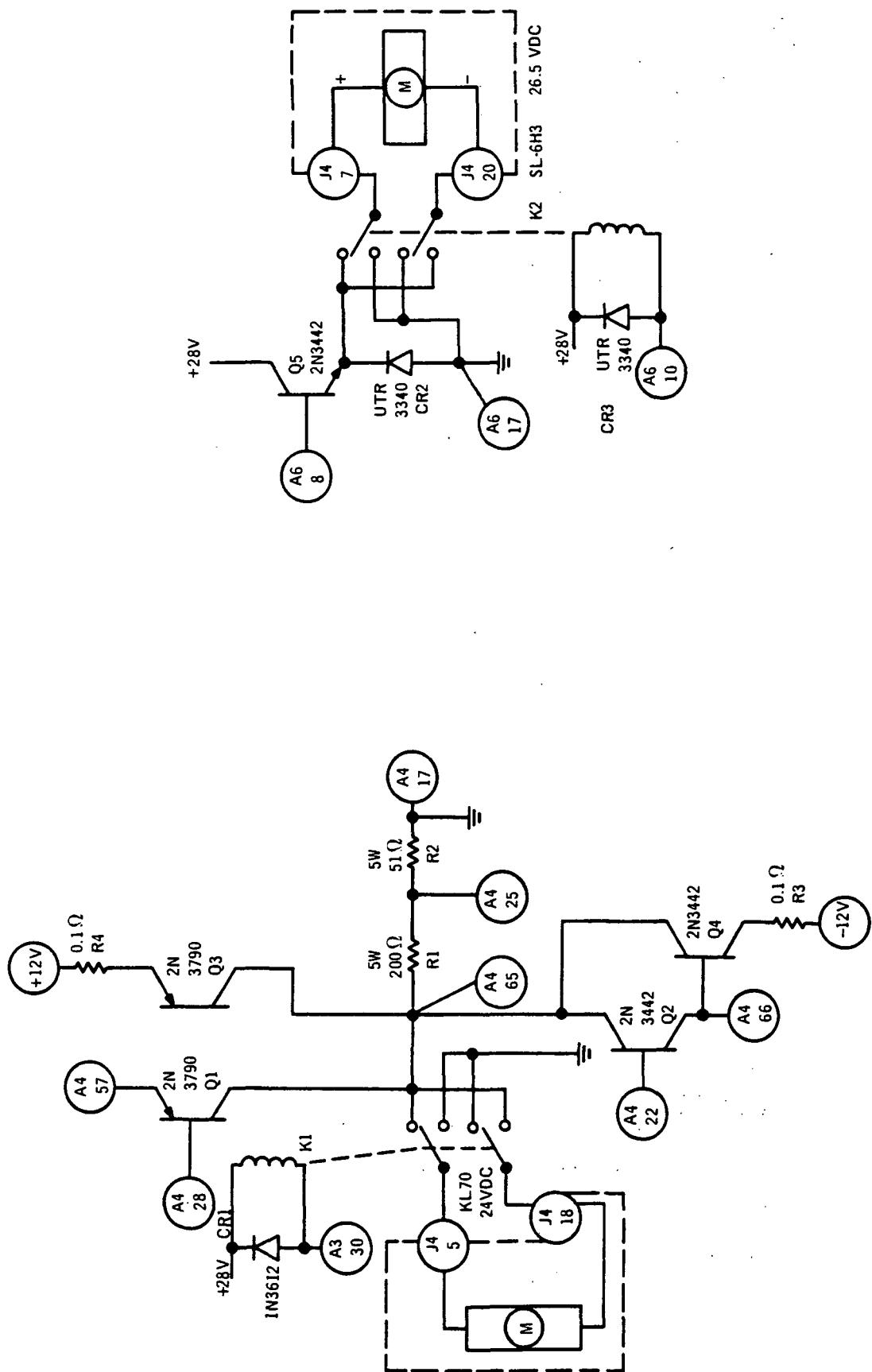
Fig. 3-21. Motor drive, schematic diagram (sheet 4 of 5).
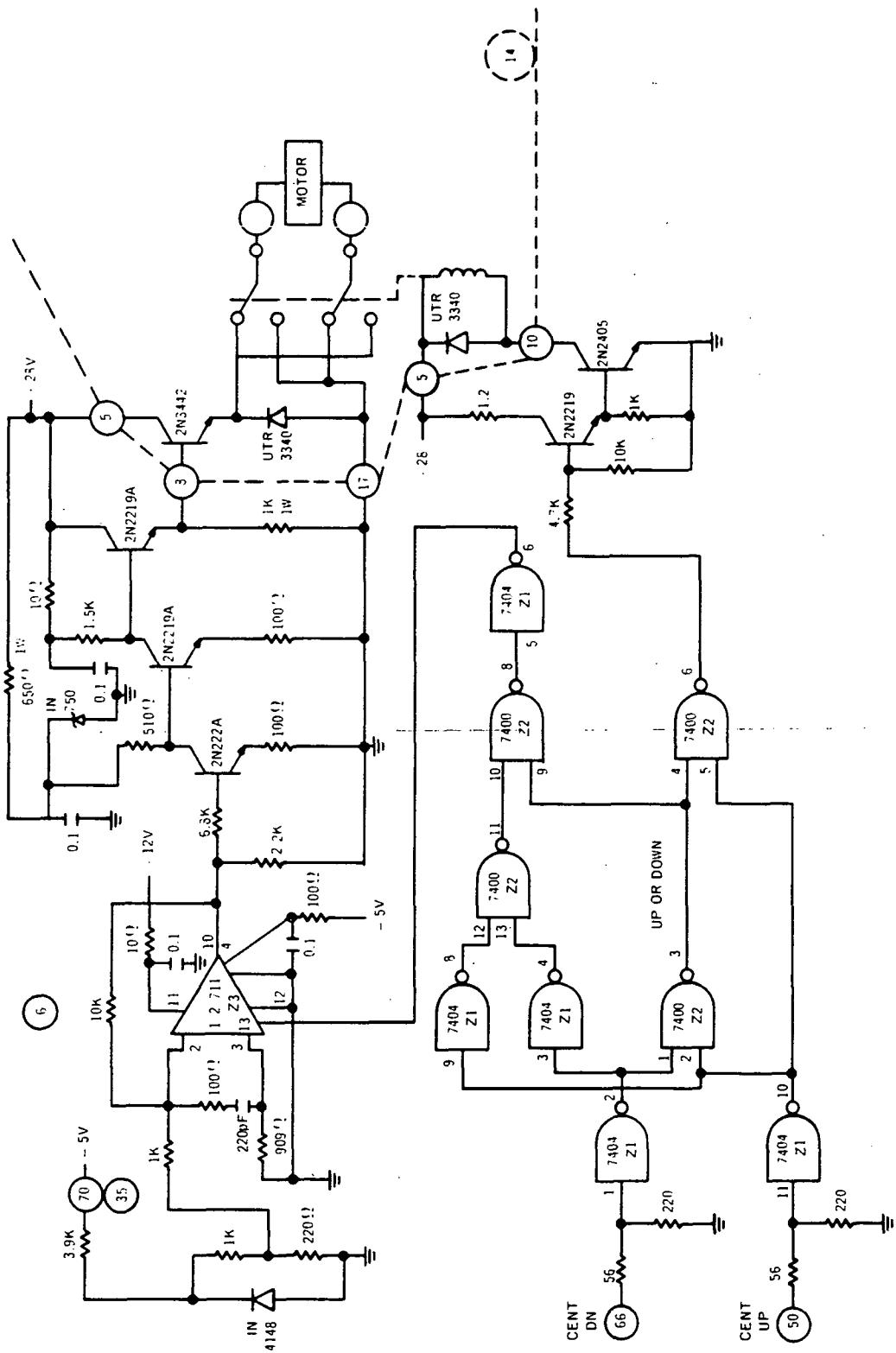
Fig. 3-21. Motor drive, schematic diagram (sheet 5 of 5).

The schematic shown in Fig. 3-21, sheet 2, shows the second phase detector which is made up again of 3 IC's and is used to control the phase reference of the VCO and the tachometer signal feedback from the transport. Again, the 9602 one-shots are used to provide a good, clear, sharp pulse for the phase detector.

## F. TRANSPORT MECHANISM

A schematic representation of the transport mechanism is indicated in Fig. 3-22. This mechanism employs a single dc motor to drive two tape reels and a capstan located near a film gate. Power is transferred from the motor through a clutching mechanism which transfers the shaft drive to an upper or lower pulley. The upper and lower pulleys are belted through different belting ratios to pulleys on either end of the motor shaft to afford a 35:1 speed variation by activation of the clutch. The lower pulley provides a speed stepup 1:5 while the upper pulley provides a speed reduction 7:1. In a continuous motion mode, the dc motor can be operated over a speed range of about 35:1 producing the required 1300:1 continuous drive speed variation.

An optical tachometer is connected to the lower pulley arrangement and essentially measures the motor speed variation through a stepup 1:5. The tachometer generates 2000 pulses per revolution. The tachometer signal is fed to the drive electronics for use in a feedback system to control the speed of the motor.

The drive shaft is coupled to two tape reels (which interchangeably act as supply and takeup reels) by means of equal length belts which drive the reels at the same speed and by a third belt to the capstan through a brake mechanism. When all of the tape is reeled on one reel and the tape set in motion, the rate at which the film moves through the film viewing area is determined by the capstan speed. The full reel, reel number one, under this condition is supplying tape at a faster rate than required by the capstan, while the empty reel, reel number two, is not accepting tape at the rate at which it is passing through the capstan; consequently if no corrective action is taken, slack would develop in the tape on both sides of the driving capstan. To prevent slack from developing and to maintain a flat film through the film gate, two tension arms are employed to take up film and maintain a uniform tension on the tape. When the two reels contain the same amount of tape, reel one is supplying tape at the rate required by the capstan while reel two is collecting tape at the desired rate; the tension arms are fully extended as indicated by the dotted lines of Fig. 3-22. The condition reverses when the takeup reel has more tape on it than the supply reel. For this case the supply reel is not supplying tape at the rate demanded by the capstan and the takeup reel takes up tape faster than the capstan supplying it. The tape loop formed by the tension arm is reduced as the tape is reeled on the takeup reel. Consequently, with all of the tape on either the takeup or supply reel, the tension arms are in the fully retracted position.

TENSION ARM
EXTENDED POSITION

TENSION ARM          FILM GATE     CAPSTAN          TENSION ARM

REEL PIVOT                                          REEL PIVOT

MAIN DRIVE SHELL

CLUTCH

- - - -  KAPTON
- - - -  BELTS

MOTOR

TACHOMETER
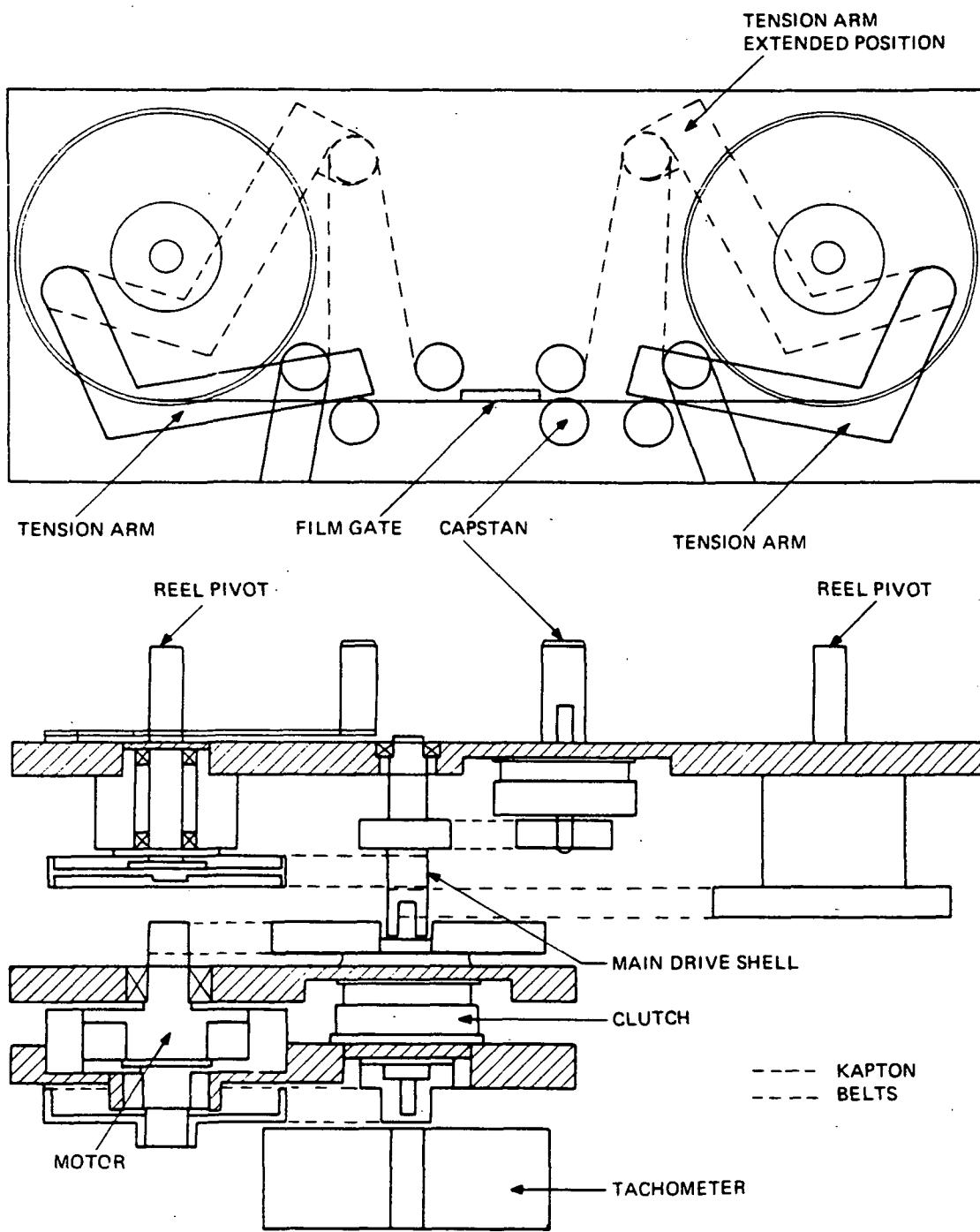
Fig. 3-22.   Transport mechanism, schematic diagram.

During the rapid retrieval mode of operation the drive shaft is engaged on the high speed side of the clutch. The clutch is only reversed when the mode is shifted to the low speed or "creep" mode. Braking from high speed is accomplished by reducing or reversing the current to the motor and allowing the motor to decelerate from a speed which produces tape motion at a rate of 1300 mm/s to a rate of 13 mm/s, at which rate the drive circuitry again causes the motor to run at a constant speed. The motor runs at this speed until the center of the desired frame is located; at which time the current is momentarily reversed in the motor and the mechanical brake is thrown causing a rapid deceleration of the holographic tape, stopping the tape at the desired indicated location.

The transport system as constructed is a highly reliable device which will require a minimum amount of maintenance. This is assured through the use of sealed bearings and a Kapton belt. These belts are good for $10^8$ belt cycles with temperatures approaching 850° C. Belts of this type are similar to a mylar belt, but have a higher tension torque and temperature characteristic than conventional belts.

## G. UP—DOWN MOTION

Levitation of the transport is used to translate the image in the Up — Down direction. The mechanical levitation of the transport is accomplished by using four unloaded ball screws located near or at each corner of the transport. These ball screws are driven from a gear train by a pick belt; they move the platform 0.05 inch for each revolution of the ball screw. The gear train provides a 485 to 1 reduction from the motor which is turning at approximately 15,000 rev/min. This results in a maximum up — down speed of approximately 0.03 mm/s.

Levitation of the transport is stopped by limit switches. Adjustment of these switches should not be attempted since misadjustment can result in the loss of the balls in the ball screws and the destruction of the lens assembly.

The drive circuitry for controlling this motor is shown in the schematic of Fig. 3-21 and is the same circuit used for the rotation system. The input signal to this circuit varies from +1 volt to -1 volt, with 0 being a no-condition. The 711 shown in the circuit is a limit comparator circuit used as an amplifier and absolute value circuit. The following transistors are used to buffer the output signal and to obtain the necessary drive for the motor. The 710C is used to sense the polarity of the input signal. This polarity is used as a direction indication. The output of the 710 is buffered to drive relay K1. This relay is used in switching the polarity of the drive signal to the motor; as such it acts as a directional control for the motor.

## Section IV

## HOLOGRAPHIC INFORMATION STORAGE

### A. WHY HOLOGRAPHY?

Holography is a technique for recording and at a later time reconstructing optical wavefronts. The ability to record a wavefront as opposed to an image relieves the constraint that recording must be accomplished in the image plane to preserve high-frequency information.

In a wavefront (holographic) recording system it is possible, at least in theory, to enter at any plane in an optical system and record the wavefront passing through that plane. This option, when coupled with the use of phase-recording materials as opposed to conventional silver halide films, offers a number of advantages over conventional methods.

These advantages include:

(1) A technique for reconstructing images precisely registered in space independent of the position of the storage medium on which they are recorded.

(2) Redundant recording.

(3) A nonabsorbtive storage medium capable of gating large amounts of optical power.

(4) Available methods for rapidly and inexpensively duplicating holograms.

(5) A high degree of image permanance.

(6) A multiple image recording capability.

(7) High density information storage.

The ability to record and reconstruct an optical wavefront, resulting in the above advantages, is a direct result of the method of recording used to form a hologram. With this technique, information describing both the phase and intensity information related to the wavefront to be recorded is captured on a storage medium. The

information is recorded as the interference pattern formed between an information-bearing object wavefront and a reference wavefront. The information-bearing object wavefront has been modulated with the information to be recorded and (at a later time) to be restored. The reference wavefront is a constant wavefront of known characteristics which can be reproduced at a later time. The recorded interference pattern between the two wavefronts is a hologram. In order to form the interference pattern, the two optical wavefronts derived from a common coherent source--typically a laser-- must be made to interfere on a photosensitive recording medium.

## 1. Basic Holographic Forms

There are a number of types of holograms. Generally, the name given to a holographic form — Fraunhofer, Fourier, Fresnel, Focused Image, etc. — refers to the location in the optical system at which the wavefront is recorded.

### a. Fresnel Hologram

The Fresnel or near-field hologram is the most rudimentary form of hologram. A Fresnel hologram may be formed as indicated in Fig. 4-1. The output from a laser is split into two components; a reference beam and an object beam. The reference beam is shaped and directed so that it falls on a holographic recording
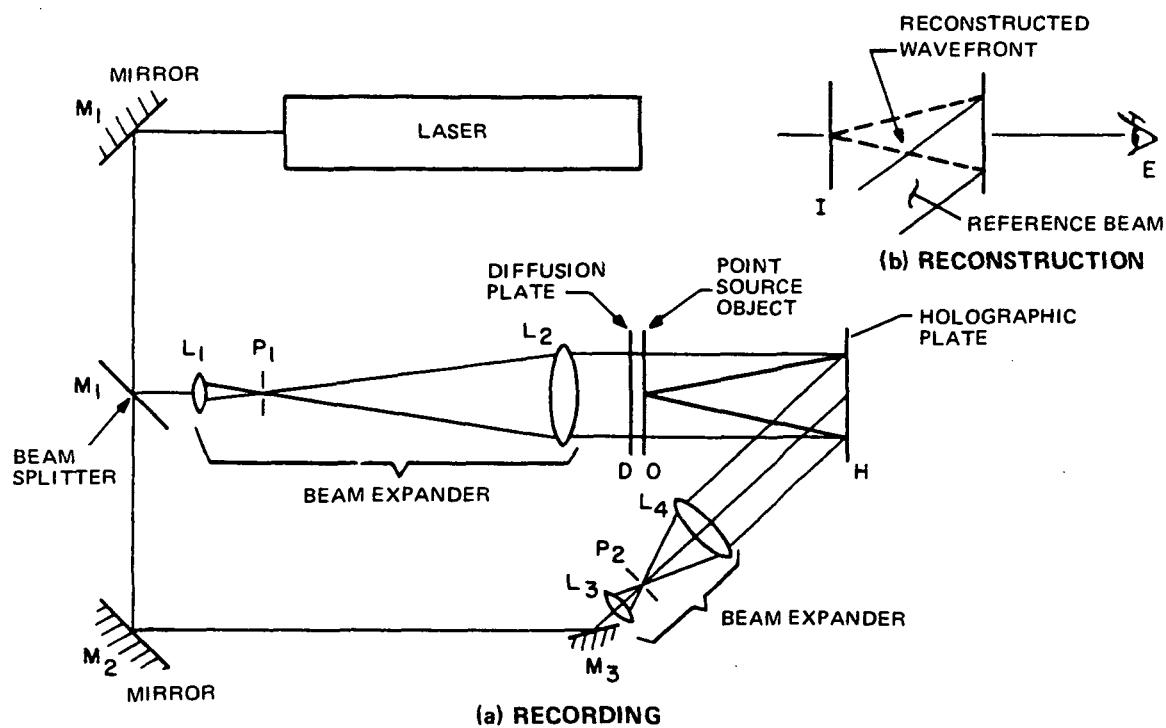


Fig. 4-1. Fresnel hologram.

plate as a plane wavefront. The object beam is shaped and caused to fall on a random-diffusion or some form of controlled dispersion plate. It is then transmitted through, or reflected from the object to be recorded. The object wavefront, modulated by the object information, falls on the holographic recording plate where it interferes with the reference beam to form an interference pattern which, when developed, is the hologram.

The information captured by the Fresnel hologram is reconstructed by first developing the plate to form a permanent record of the interference pattern and then replacing this record in the reference beam. This results in a reconstruction of the original object wavefront. If the reference beam is directed from left to right in Fig. 4-1, an object beam will be constructed propagating from left to right, resulting in what will appear as a virtual image at plane I to an observer at position E. Propagation of the reference beam from right to left will result in a real image at plane I.

The Fresnel hologram has the property that information describing a point on the object is distributed over the whole (or a major portion) of the holographic area. It is a highly redundant form of recording; scratching, abrading, or totally destroying a portion of the hologram will not cause loss of information as it would in a microfilm storage medium. The effect of scratches or abrasions on this holographic system is to raise the background noise level, while reducing the image brightness.

b.  Fraunhofer Hologram

The Fraunhofer hologram, of which the Fourier transform hologram is a special case, differs from the Fresnel hologram in that the interference pattern is recorded in the far field of the optical system. One method of recording a Fraunhofer hologram of this type is to locate the recording plate at a considerable distance (equal to many times the maximum hologram dimension) from the object to be recorded. Moving this distance from the object produces the desired far field pattern, but the fact that the recording is far removed from the object plane results in poor optical collection efficiency, thus requiring long exposure times.

To offset the long exposure requirement, a lens is inserted in the recording system as indicated in Fig. 4-2. The lens, placed at a distance equal to its focal length from the object, converts the wavefront intercepted by the lens to the desired far field pattern. This pattern, recorded at any location on the far side of the transform lens, produces a Fraunhofer hologram. If the recording is made a focal length away from the lens (in the Fourier transform plane), the hologram is called a Fourier transform hologram.

The Fraunhofer and Fourier transform holograms, since they are recordings of wavefronts captured in the far field, are image motion insensitive.

The reason why this occurs becomes obvious if one considers the optical system of Fig. 4-3. Here a point source $P_{S1}$ is collimated by lens, $L_1$, to form a plane wavefront. If the solid ray trace is considered first, it can be seen that a lens $L_2$ of the same focal length as $L_1$ will form an image of the original source at a $P_1$. If the lens and source are translated upward a collimated wavefront defined by the dotted ray trace will be formed, but although the wavefront has been translated upward, it will still be focused to the same point image. Motion of the lens-source combination into and out of the plane of the paper will produce the same effect.

The displacement, on reconstruction, of a hologram formed between lenses $L_1$ and $L_2$ produces the same effect as moving the lens and source combination, and consequently exhibits the same trait of producing a stable, registered, reconstructed image although the storage medium may be displaced or moving.

If the hologram is translated in X or Y the restored wavefront still strikes the reconstruction lens at the same angle, but at a different location, producing an effect similar to that produced by the motion of the lens in Fig. 4-3. If the motion is such that a different hologram is brought into the field of view the information stored in the original frame dissolves into that of the second frame. There is, however, no apparent image motion. The above discussion is extended to a complex object by considering the complex object as a collection of points.

Thus, <u>holograms recorded in the far field produce, upon reconstruction, images which are independent of the lateral displacements of the hologram, as long as the reconstruction beam passes through both the hologram and the restoration lens.</u> The location of the reconstructed image is independent of the position of the storage medium.

Generally, when storing information in which low-frequency terms are present, i.e. background area having low frequency detail which is to be preserved, the recording is done at some other point than the Fourier transform plane. This is done because, at this plane, the dc information exists as a point of high intensity which generally exceeds the dynamic range of the storage medium and which, in addition, can be seriously modified by scratches or abrasions. When recording is done at some other plane, e.g., twice the distance from the transform lens, both the dc and high frequency terms are distributed over the total holographic area. When recorded in this manner, <u>the Fraunhofer hologram is, as is the Fresnel hologram, a highly redundant technique for storing information.</u>

c. <u>System Implementation</u>

The Fraunhofer holographic type described above is used in modified forms to record frame indexing information in the Multifunction Display System. The image information is recorded as a focused image hologram. A focused

4-4
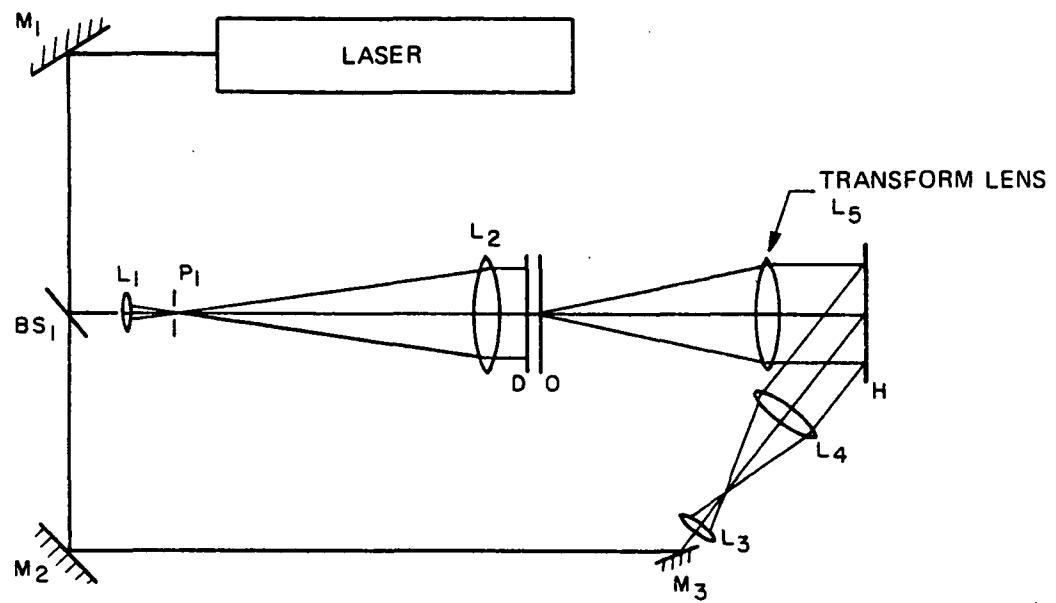
Fig. 4-2. Fraunhofer hologram.
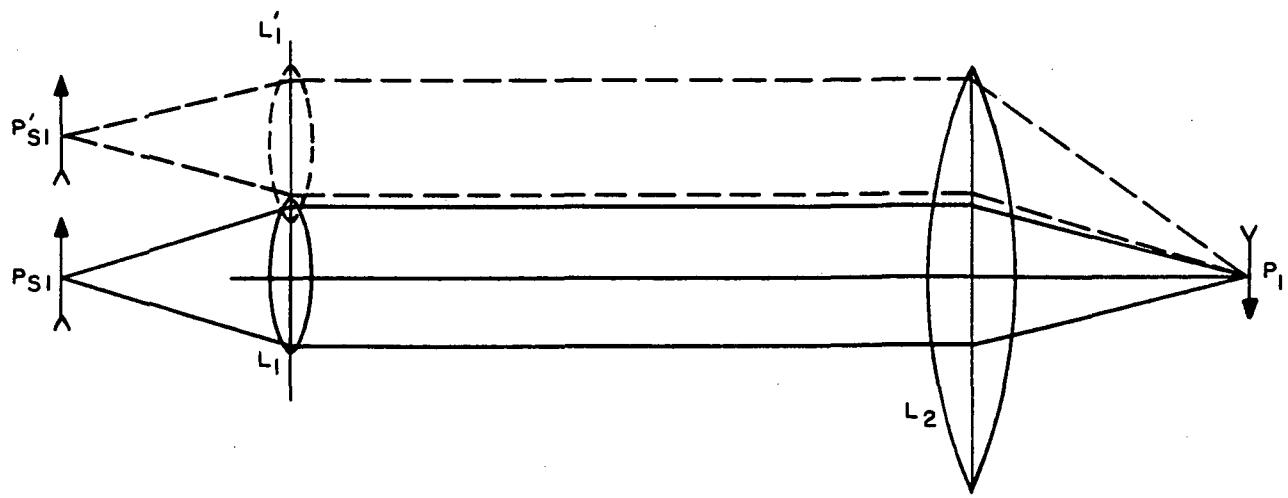


Fig. 4-3. Relay imaging.

4-5

C2

image hologram is recorded with the optical configuration of Fig. 4-4. The hologram is made in the image plane of the lens of $L_4$. This system, used to record image information, and the quasi-focused image hologram system, are described in more detail in the next section.

## 2. Phase vs. Absorption Holograms

The holographic restoration process is one in which the intensity or phase characteristics of a wavefront are modified by a recorded interference pattern to produce a diffracted wavefront similar to the recorded wavefront.

Consider the effect on a wavefront propagated through a sinusoidal absorption grating. As indicated in Fig. 4-5, light is diffracted into the plane wavefront. (Additional wavefronts are also formed which are not shown.) The angle of diffraction $\theta$ is equal to the angle whose sine is $\frac{\lambda}{\delta}$, where $\lambda$ is the wavelength of the optical signal while $\delta$ is the grating pitch. This is the normal diffraction equation for a sinusoidal grating. (A binary or square wave grating is characterized by an addition of higher order terms.)

It can also be shown that if plane optical wavefronts are allowed to interfere as indicated in Fig. 4-5(b) a sinusoidal grating is formed having a pitch

$$\delta = \frac{\lambda}{\sin\theta}$$



Fig. 4-4. Focused image hologram

4-6

RECONSTRUCTION
WAVEFRONT

GRATING

DIFFRACTED
WAVEFRONT
(−1 ORDER)

θ

(a)                                    (b)
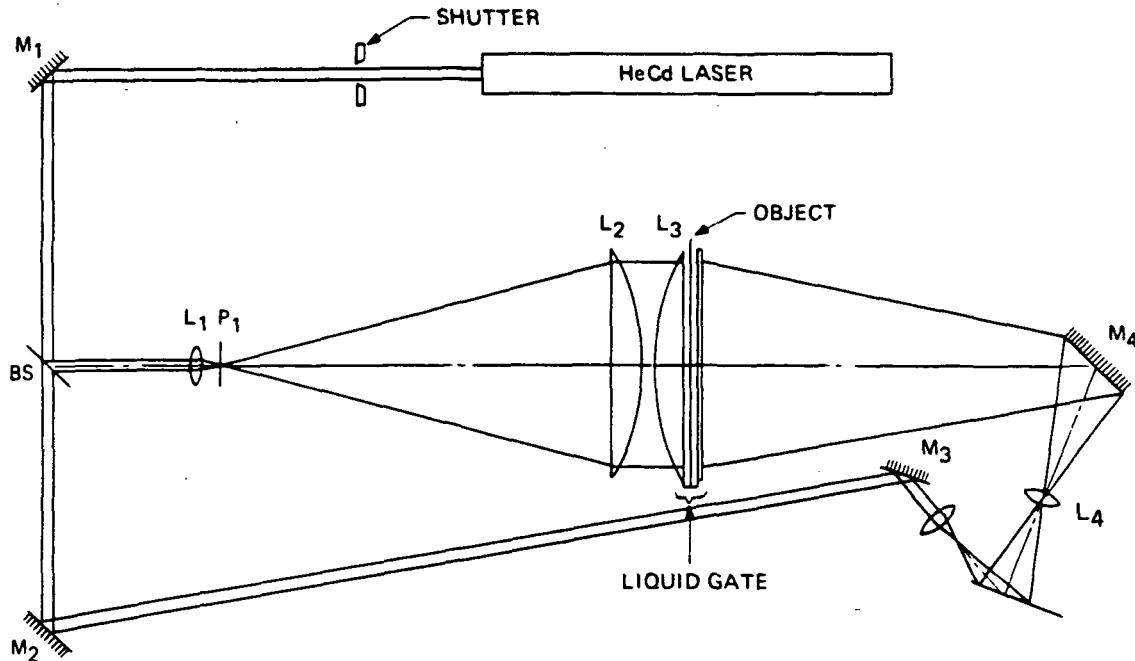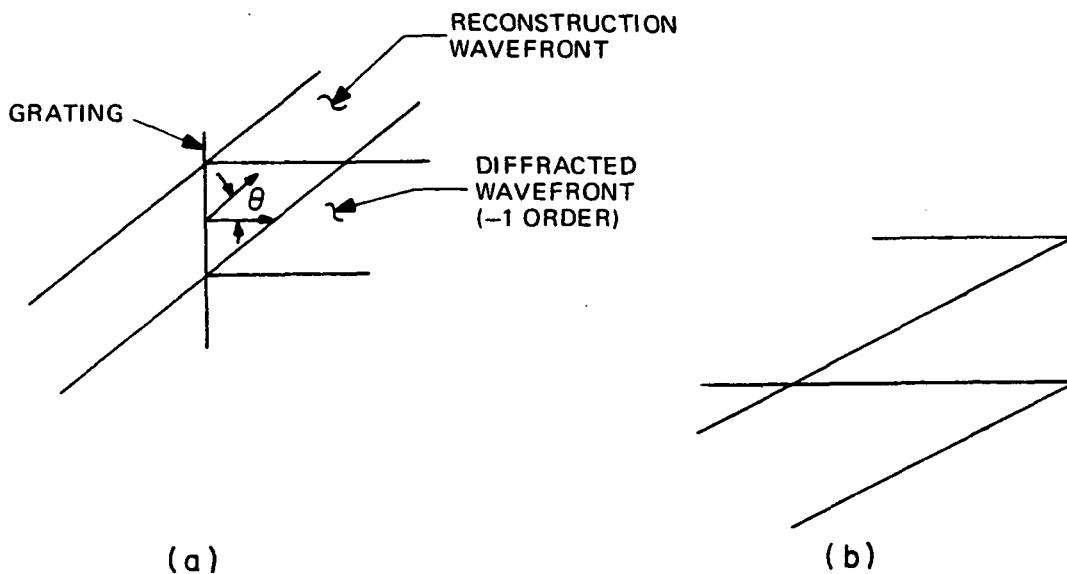
Fig. 4-5.  Diffraction effect.

Thus, the reconstructed wavefront and the wavefront used to produce the grating are
the same.  This is the essence of holography.  All holograms consist of no more than
the superposition of a series of gratings forming a complex interference pattern which
when interrogated by a reference beam similar to the reference beam used to form the
complex grating causes a diffraction effect which produces a reconstruction of the
original object wavefront.

The diffraction effect described above assumes the use of an absorption
grating.  It can be shown[1] that the same effect can be produced by modulating the
phase characteristics instead of modulating the intensity characteristics of the
reference wavefront.  A phase grating or hologram as indicated in Fig. 4-6 is used
to produce the effect.  Whereas absorptive holograms are produced on materials
which absorb energy from an optical wavefront (such as silver halide films and
photochromics), phase holograms are formed in materials which produce a phase
variation in the optical wavefront as the wavefront is transmitted through or reflected
from the storage materials.  Materials such as photoresists, thermoplastics of
the thin film materials, and $LiNbO_3$ and $Ba_2NaNb_5O_{15}$ of the volume recording
materials are commonly used phase materials.

During the course of this program, RCA made exclusive use of photoresist
(similar to Shipley AZ-1350) as the recording material.  This material was selected as

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[1.] Born, M., and Wolf, E., Principles of Optics, Pergamon Press, 1959.

0.001 mm (TYPICAL)
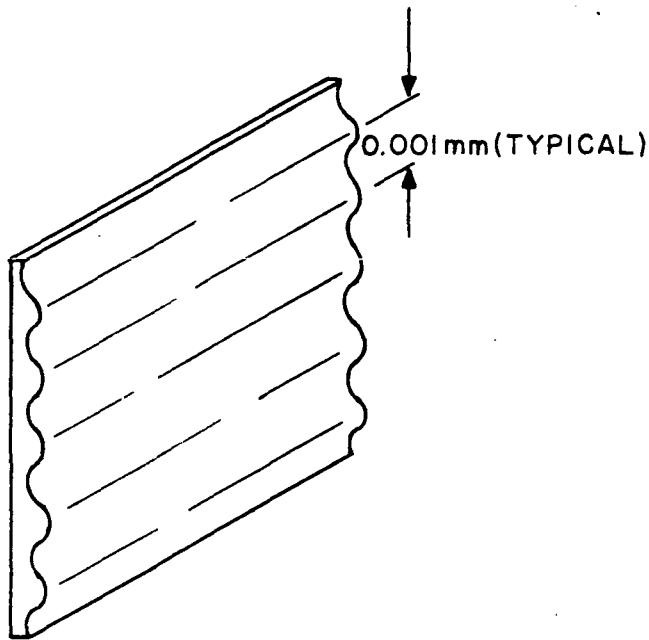
Fig. 4-6. Sinusoidal phase grating.

a result of the materials studies performed by RCA on previous holographic storage programs. Photoresist produces a phase hologram as a relief image on the surface of the material. Photoresist has the property that its solubility in a developing solution is a function of its history of exposure to light. The material used to form the holograms for the multifunction display is a positive material, i.e., where the material has been exposed to optical energy it is washed in the developing process at a faster rate than the unexposed areas, forming a relief image on the surface of the photoresist a fraction of one wavelength thick.

The fact that the hologram is formed as a relief image allows the implementation of an inexpensive duplication process. The photoresist master is used to form a nickel embossing master. The embossing master is generated by depositing silver on the holographic surface by either a chemical or vacuum deposition process. (Both have been successfully employed by RCA.) The silvered hologram is then used as an electrode in an electrolytic plating process. This process builds up a nickel plating layer several mils thick. The resulting metallic plating is easily stripped from the photoresist and is used as an embossing master to transfer the original hologram to an inexpensive storage medium.

In applications where temperatures of 60°C are not exceeded, such as in the computer environment at the multifunction display, an inexpensive vinyl material is employed as the storage material. Where high temperatures are encountered, lexan or acetate materials may be employed. A single recording master may be used to produce literally tens of thousands of copies on these materials.

4-8

In this manner another important advantage of holographic recording is realized; by employing a phase material which produces a relief image hologram, holograms can be rapidly and inexpensively duplicated.

An additional advantage of phase recording is that, as opposed to conventional recording where information is displayed by modulating the intensity of an optical wavefront by absorbing energy from that wavefront, a phase hologram modulates the optical wavefront by changing its phase characteristics. The fact that the storage medium does not absorb energy allows the hologram to gate large amounts of optical power without causing overheating of the storage material. In a conventional system this overheating causes the film to pop in and out of focus (thermal distortion) and, in more severe cases, destroys the recorded information. Thus, the hologram can be used to gate large amounts of optical power.

Further, the embossing process is permanent (if the proper material is selected) as long as the temperature of the material is kept below its flow temperature. The fact that power is not absorbed in the storage medium prevents such temperatures from being reached except when the environment is allowed to reach these temperatures. Thus, for most applications, the recordings are stable and permanent; when used for the display of multicolor information the colors do not fade.

Thus, an additional advantage is attributed to holographic storage, a permanent, archival storage technique.

A final advantage of holographic recording is that multiple images can be stored in a common recording area while recording at high densities. A technique is described in the following paragraphs in which three elements of a color separation set are recorded in a common area.

Offsetting these advantages are several disadvantages which must be overcome in the development of a practical system. A coherent (laser) light source is required to construct the holograms, although it is not necessarily required for reconstruction. The recordings must be made in a vibration-free environment, since only in this type of environment can stable interference patterns be formed.

In summary, holography is an attractive system for the storage of image information because it offers a number of advantages not found in more conventional recording techniques:

(1) A technique for reconstructing images which are precisely registered, independent of the position of the storage medium on which they are recorded.

(2) Spatially redundant recording.

(3) A nonabsorptive storage medium capable of gating large amounts of optical power.

(4) Available methods for rapidly and inexpensively duplicating holograms.

(5) A high degree of image permanence.

(6) A multiple image recording capability.

(7) High density information storage.

These advantages make holography a prime contender for the information storage system of the future.

## B. RECORDING SYSTEM IMPLEMENTATION

### 1. Hologram Selection

A requirement of this program was to produce a color image storage and display system employing a technique suitable for storing information so that it can be rapidly accessed and a display with adequate brightness for viewing in a brightly lit room without requiring laser source for reconstruction of the displayed image. Of the variety of techniques considered, only the focused image and quasi-focused image holograms of the thin film holographic forms, and the Bragg holograms using volume recording techniques, were found to allow reconstruction using incoherent, white light sources.

The volume techniques were rejected after a brief consideration for two reasons. First, at the time of the inception of this program there were no volume storage materials available which possessed sufficient stability and material uniformity to produce holograms possessing a quality compatible with the moving map dislpay requirements. The second reason (which is probably more important for the present application) is the lack of a technique which allows the production of inexpensive copies of the holograms stored in the volume materials. Effort is being expended on attempts to develop solutions to this problem on a related Navy-sponsored program being conducted at RCA Laboratories in Princeton, N.J.* This program shows the promise of developing stable materials of high quality which can be fixed for permanent storage.

With the problems listed above, a question is raised as to why one would even consider the volume materials, particularly since both of these potential problems have already been solved for other methods of recording. The answer is that if methods of effectively recording and duplicating stable volume holograms are developed, enormously large volumes of information could be stored in a small storage volume, for example maps of the world at 500,000:1 and 2,000,000:1 could be stored in a small cube several millimeters on a side.

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* Contract N00019-72-C-0147, "Materials for Phase Holographic Storage"

Although the potential for such materials is great, the facts remain that these materials are new and that much work remains to be accomplished before volume type materials will be available for practical use in field systems. For this reason the decision was made to record using thin film holographic techniques. In thin film recording the holograms are recorded in materials to a depth of only a fraction of a wavelength. This is the condition that exists when absorption holograms (i.e., holograms that record the interference pattern making up the hologram on a material which when developed absorbs information from the optical wavefront) are recorded on materials such as unbleached silver halide films and photochromics, and when phase (i.e., holograms that record the interference pattern making up the hologram on a material which when developed affects the phase characteristics of the restoration wavefront to reproduce the stored wavefront) are recorded on materials such as bleached silver halide emulsion, photoresists and thermal plastic.

If materials such as photoresists or thermal plastics are used as the original storage material, phase holograms are recorded as interference patterns which appear as relief patterns a fraction of a wavelength deep on the surface of the material. Holograms recorded in this manner can be inexpensively duplicated.

Thus, after considering a variety of holographic recording techniques, two related thin film phase hologram techniques were possible candidates for use in the Multifunction Display System: these are the focused image and quasi-focused image recording techniques. Both of these forms are recorded in the near field and as such produce an image which moves as does the recorded hologram.

2.  White Light Restoration of Focused and Quasi-Focused Image Holograms

The white light holographic restoration process is worth discussing further since the white light restoration of holograms may be a new concept to some readers. Holograms are generally considered as a recording of the interference pattern between two optical wavefronts which is produced only when the two wavefronts are derived from a common coherent source - which is true, and which can only be restored using a coherent source - which is not true.

White light reconstruction is described by first discussing conventional imaging system. The parallels between this system and a focused image hologram are developed. Coherent light resoration is next considered; finally, the techniques which are employed to display quasi-focused image holograms using coherent and white light sources are discussed.

Consider a conventional photographic projection system as shown in Fig. 4-7.

In this system light from an optical source passes through an object located at plane A and is imaged by an imaging lens, L, to form an image of the object at plane B. Information is impressed on the optical wavefront which transfers the information
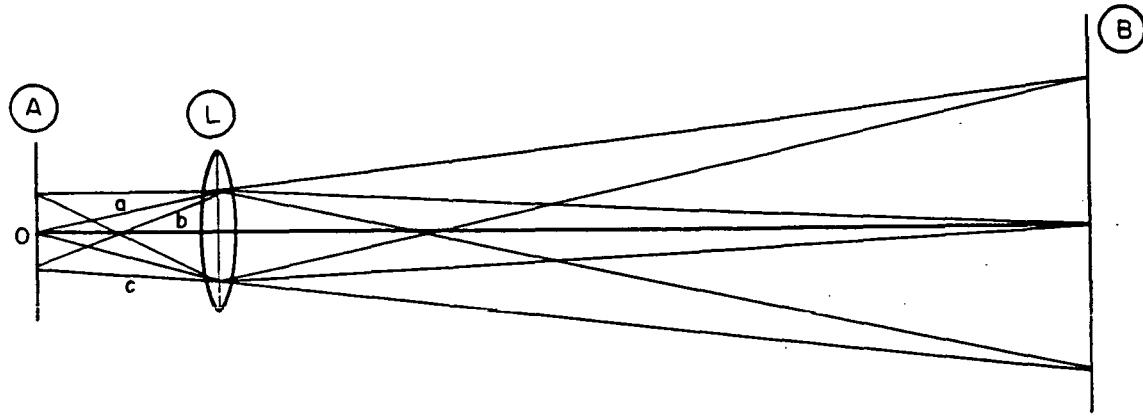
Fig. 4-7. Conventional imaging system.

necessary to describe the object from the object to the image plane by spatially modulating the intensity of the optical waveform as it passes through the object. For the case shown, a spot at point b is imaged to a focused magnified spot in plane B.

Consider now a holographic system. A hologram (as previously defined) is a recorded interference pattern formed between two coherent wavefronts. The hologram, when interrogated by one of the wavefronts either in a transmission or reflection mode, leads to a reconstruction of the second wavefront. The result is that one can record an optical wavefront in any plane (in theory) within an optical system and is thus free from many of the constraints imposed when recording only in the image plane.

A coherent source (a source derived from a laser) is required to form the holographic recording. However, a coherent source is not required to read the hologram. Recording is accomplished by forming an interference pattern between two wavefronts. The interference pattern will be formed only if the two wavefronts are derived from a common coherent source such as a laser. The recorded interference pattern in general consists of complex superposition of a series of diffraction gratings. The superimposed gratings may be read out by a coherent reference beam or by a beam which is derived from a white light (or black body) source, and which consequently is incoherent. The physical action which produces a diffraction effect, which can be observed when one views a point source of light through a fine screen, occurs for coherent sources as well as for incoherent sources.

A problem occurs when attempting to read out most forms of holograms in that optical energies of different wavelengths are read out at different angles, since the diffraction angles are wavelength-dependent. This effect generally results in a reconstructed image which is severely chromatically aberrated; aberrated to the point where it can not be deciphered. There is, however, a form of holographic recording which does not suffer from this fault: the focused image hologram technique.

In this system, illustrated in Fig. 4-8, a white light point source at point O is used to interrogate the holographic recording. For a small spot located at point b, the recording consists of a small grating which intercepts a portion of the energy contained in the cone a, s', c and, due to the diffractive properties of the grating, directs the energy into the aperture of lens L. Two ray traces, a dotted and a solid, are indicated to define the diffracted energy cones from the red (dotted) and blue (solid) portion of the spectrum. Colors between these two extremes produce ray bundles which are positioned closer to the optical axis than the two extremes shown. In the configuration shown, energy passing through the spot on plane A which is diffracted through the lens is imaged in registration to a focused spot on plan B. This occurs regardless of the section of the lens through which is passes. This then, results in the formation of registered red and blue images. In this configuration, the focused image hologram configuration, incoherent white light sources can be used to directly read out the focused image holograms. The refraction and imaging process is similar for both phase and absorption holograms.
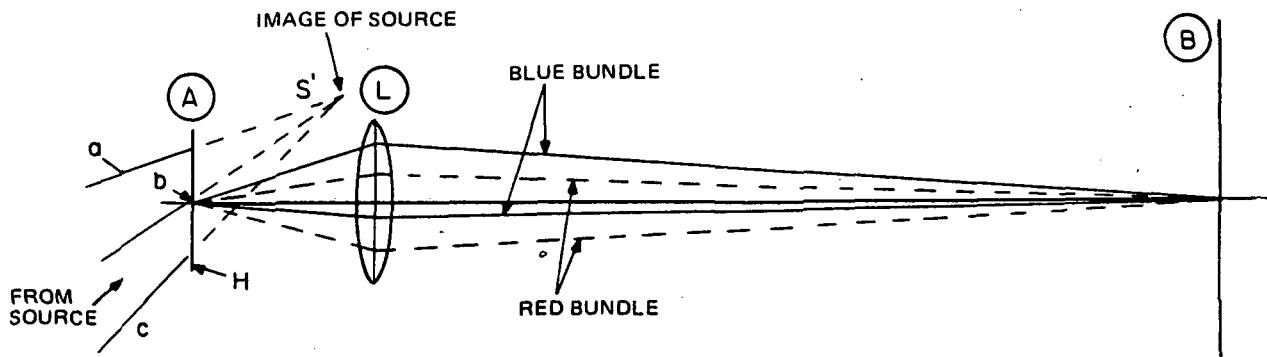


Fig. 4-8. Focused image hologram reconstruction.

### 3. Full Color Image Storage

To this point the discussion has been concerned with the reproduction of a single color hologram. The effect of using a broad spectrum source and methods of properly precorrecting the source so that the stored information can be read out have been considered, but the method of producing a full color display has not been detailed.

In the Multifunction Display System information necessary to reconstruct full color images is stored in three separate holograms recorded superimposed in a common holographic storage area. Three color separations, a red, a blue and a green, are derived from the information to be recorded. The three separations are recorded in succession in the common holographic area with the reference beam falling on the holographic plate at a different angle for each recording. The reference beam is formed as indicated in Fig. 4-9 such that it has a sperical wavefront with a radius of curvature identical to that of the dc term of the object wavefront passing through the imaging lens. In the configuration shown in Fig. 4-9, a
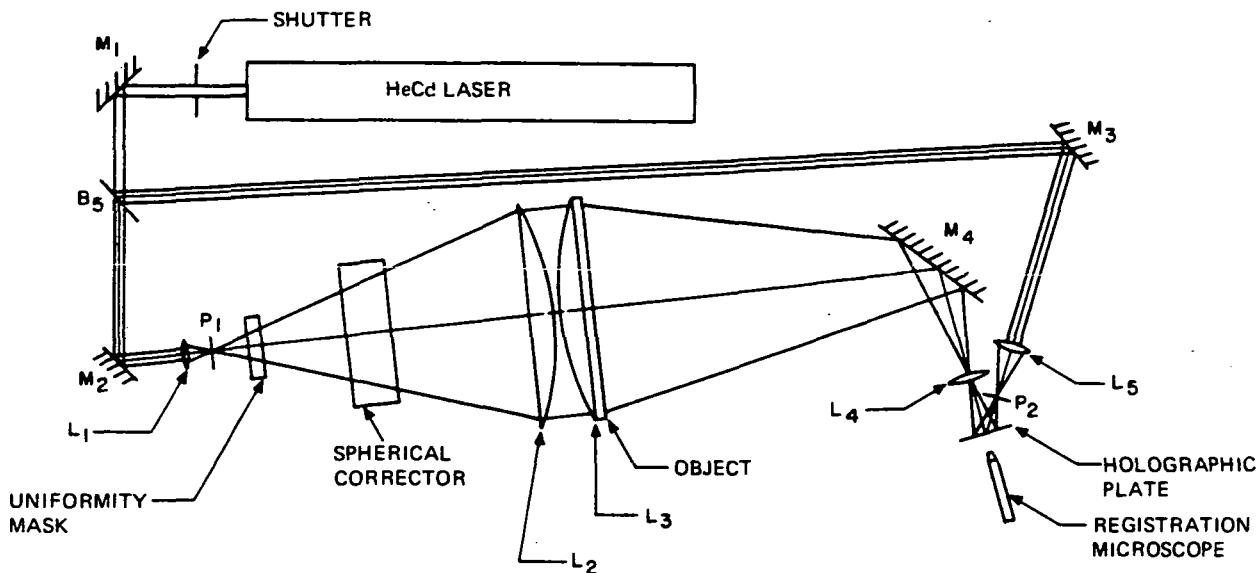
Fig. 4-9. Focused image recording system.

HeCd laser is used as the coherent reference source. The beam developed by the laser is split into two paths, one used for establishment of the object beam while the second is used to form the reference beam. The object beam is passed through a beam enlarging system ($L_1$, $L_2$) which has an included pinhole used as a filter to eliminate imperfections in the beam caused by defects in the optics of the laser, the mirrors and lenses which operate on the beam. The enlarged beam is then passed through the condenser lens and then the object, an element of a transparent color separation set. A condenser, $L_3$, collects the light passing through the object and directs it to the aperture of an imaging lens, $L_4$. The imaging lens forms an image of the object on the holographic plate. The reference beam is focused by means of $L_5$ to the pinhole, $P_2$. It is allowed to expand beyond the pinhole and thus to strike the holographic recording plate with the desired radius of curvature.

The use of a spherical reference wavefront to form an interference pattern with the dc term from the object produces a pattern consisting of a linear grating. (If $P_2$ were coincident with the principal back plane of the lens $L_4$, the fringe pattern would be of uniform pitch. The fact that $P_2$ is off the main axis produces a fringe pattern of varying pitch. Close examination of the holograms supplied with the moving map display will show this effect.) High frequency information in the object will result in a fringe pattern which deviates from the straight line fringe structure characteristic of the dc term. This deviation produces the high frequency information in the restored image. For the recording and playback angle employed in the multifunction display, this deviation reaches a maximum of less than ±10° for information which, when displayed, will have a resolution of 10 lp/mm or less.

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Thus multiple frames of information can be recorded in a common area by changing the orientation of the fundamental grating structure.

In the recording system employed by RCA the grating structure orientation is changed by maintaining the optical elements in a fixed position and rotating the object and the holographic plate between each recording. A typical recording operation is performed in the following manner. The blue color separation is mounted in the object plane with its north axis pointing up (0°). A holographic plate is entered in the recording plane (focal plane of the imaging lens if focused image, or in front of or behind the focal plane if a quasi-focused image hologram is to be recorded) and a recording made. The plate is then rotated 45° and the green color separation entered in the object plane as before, but with the north axis rotated 45° in the same direction as the holographic plate, resulting in a recording of the green information superimposed over and registered with the original blue recording. The third, or red color separation is recorded over the blue and green holograms with the photographic recording plate and object rotated 90° from the original recording position.

The result is the recording of three grating structures which may be simultaneously read out with red, blue and green reconstruction beams falling on the hologram at the proper angles to diffract the red, blue and green image information down the optical axis. This forms three superimposed red, blue and green images, or a full-color image in the viewing area. (If only black and white information is to be recorded, a fourth grating orientation is used and a single recording is made.)

The reconstruction processes for the full color focused image and quasi-focused image hologram are the same, except for one additional element; if the quasi-focused image hologram is employed, the reference beam must be predispersed before it is passed through the hologram.

This recording and reconstruction process, and the method of implementation, are discussed in more detail in following paragraphs of this report.

The focused image holograms supplied with the model were recorded in the laboratory setup shown in Fig. 4-10 and 4-11. This setup is designed to record 8 1/2-in by 8 1/2-in image segments as 12-mm by 12-mm holograms. The recording is accomplished as a phase hologram on photoresist. The setup shown is used to record the image information; a second setup described later is used to record registration and indexing information.

Figure 4-9 is a schematic diagram of the focused image recording system. The keys on this figure correspond to the keys indicated in Fig. 4-10 and 4-11. In this system a HeCd laser is used as the coherent recording source. The beam, as it emerges from the laser, is passed through a shutter and thence via a mirror to a beam splitter. The beam splitter forms two beams, one directed toward the lens $L_1$ and the second down the path including the mirror $M_3$, the lens $L_5$, and the pinhole $P_2$.
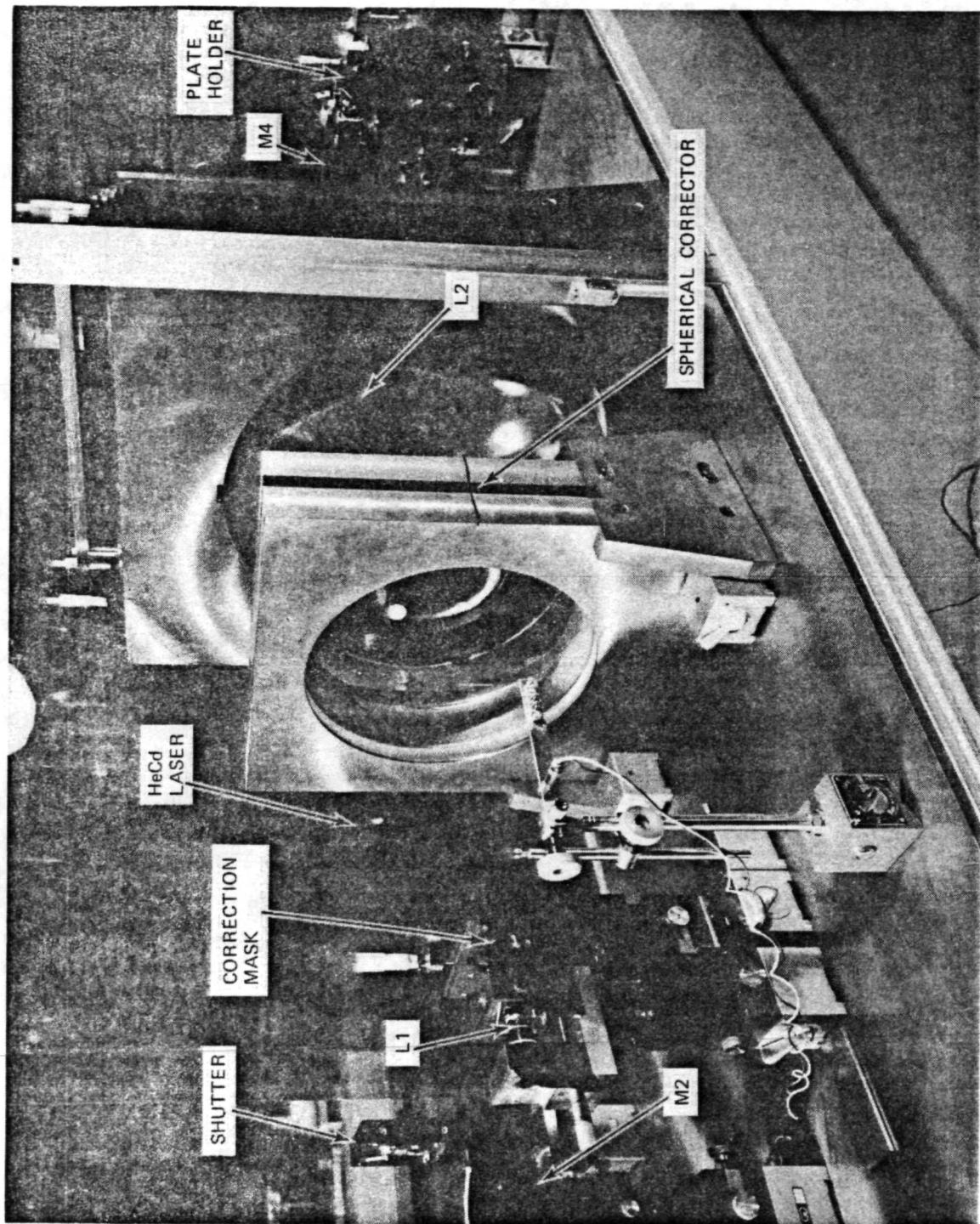
Fig. 4-10. Focused image recording–laboratory system (view 1).

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Fig. 4-11. Focused image recording–laboratory system (view 2).
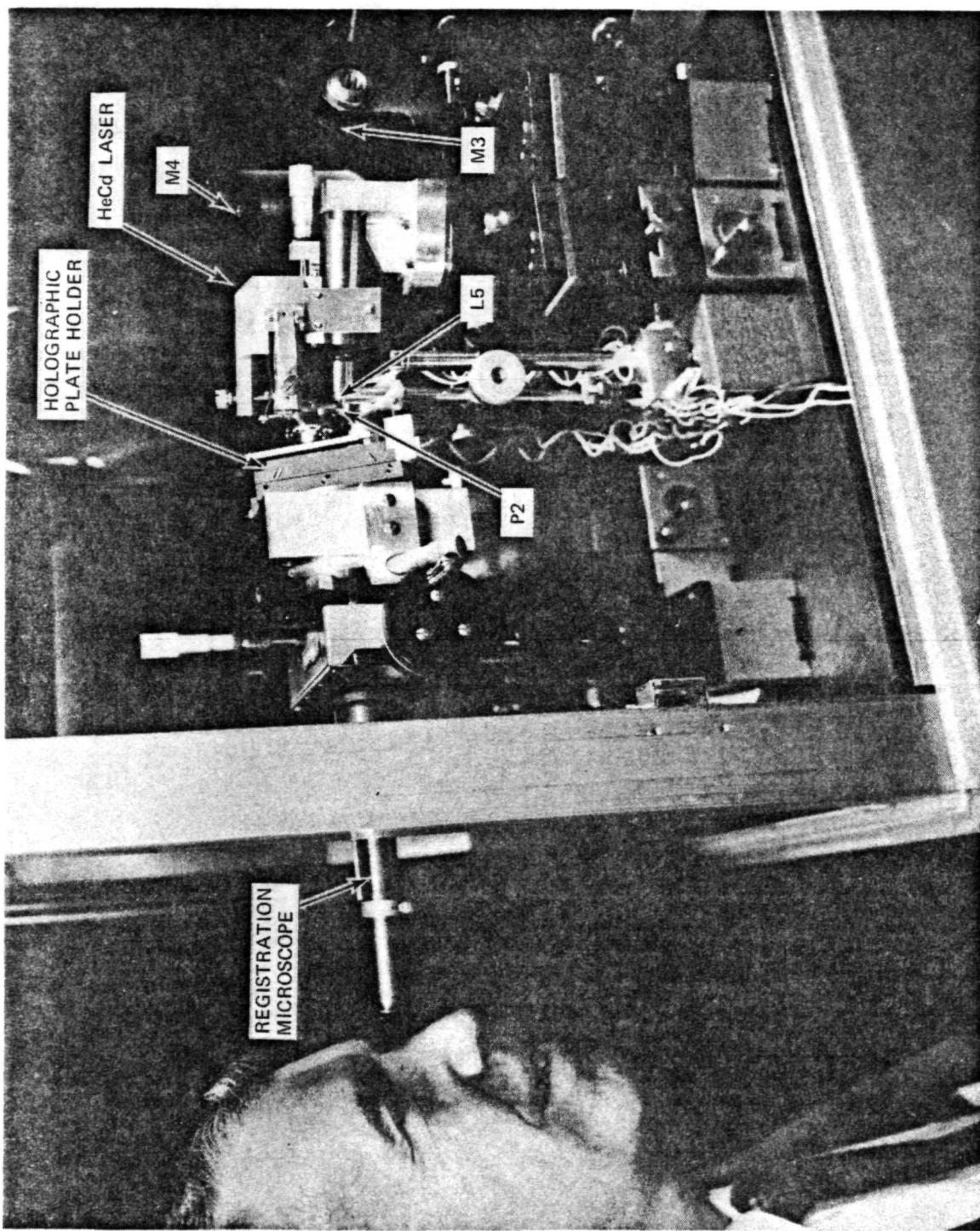
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The lenses $L_1$ and $L_2$ establish an expanded object beam which is passed through the condenser $L_3$. The pinhole $P_1$ is used to clean up the object beam, eliminating inhomogeneities in this wavefront. Ideally, the object transparency should be located between the two condenser lenses. No degradation in system performance is introduced, however, if the object film is moved to the far side of the condenser lens pair. This is done in the implemented recording system so that the flat surface of the planoconvex condenser element can be used as a mounting surface for the object film transparency. The condenser system consists of two planoconvex lenses 18 inches in diameter. The optimum performance (i.e., essentially no geometric distortion) is produced by the lens pair when they are operated with their spherical surfaces facing each other.

The light passing through the condenser lens and the object is directed toward the image plane where it is focused by means of the imaging lens, $L_4$, to the recording plane. The lens $L_4$ in this path is a 80X microscope objective. The pinhole is about 3 microns, the condensers are spherical, 18 inches in diameter, and have a focal length of 34 in. The imaging lens is a modified f/3.5, 32-mm lens purchased from General Sciences of Chicago, Illinois.

The reference beam is passed through a beam shaping telescope assembly and is made to strike the holographic plate with a radius of curvature of the same shape as that of the dc term passing through the imaging lens. This beam forming lens is an 80X microscope objective similar to that used in the reference beam. For this program the holographic plate holder is designed to hold glass plates with photoresist deposited on the side toward the lens systems. The holder is shown in Fig. 4-10.

The objective holder is designed as a liquid gate, based on anticipated problems with the film uniformity of the color separations resulting in spurious interference patterns in the restored image. A pinning arrangement is located at the top of the film holder to pick up two precision registration pinholes on the film separations. The registration pinholes on the color separations are designed at the proper angles to produce the 0°, 35°, and 90° deviations of the north axis of the red, blue and green color separations respectively, and in this manner properly orient the separation material to allow recording of the three superimposed images at the proper orientation. Micrometer adjustment of the registration pin locations is provided to allow accurate positioning of the film and accommodate for errors in the placement of the registration holes on the color separations. After receiving the color separations to be used to produce the image holograms for delivery with the equipment it was found that, with polyester-base material, recording could be accomplished without using a liquid gate. Recording was thus accomplished with the gate dry.

A major problem encountered in the system implementation was one of obtaining adequate stability and uniformity of the object and reference beams. A major cause of nonuniformity resulted from the use of spherical rather than spherically corrected condenser lens pairs, which would have been prohibitively expensive. The procured condenser lenses proved to be spherically aberrated to the extent that it was necessary to design and build correction elements. This caused a significant delay in the recording phase of the program. The corrector, which is a doublet, and is inserted between $L_1$ and $L_2$ of Fig. 4-9, effectively corrected the spherical aberration introduced by the condenser system.

In addition to the correction lens, several additional lens elements are shown which compensate for beam nonuniformities. Also included in the diagram is a balancing mask. This mask is introduced between the pinhole and the first condenser lens to compensate for undesired intensity variations in the object beam. These nonuniformities are twofold. They result first from the Gaussian distribution of the beam as it exits from the pinhole, producing an uneven energy distribution across the object plane. The second effect is the result of defects in the pinhole. The pinhole should be round and between 2 and 3 $\mu$m in diameter. The small size is required to eliminate unwanted disturbances in the beam which would produce disturbing beat patterns in the restored image. It is, however, very difficult to fabricate an ideally round pinhole that will work with the f/2 cone produced by the microscope objective. Consequently, after a pinhole is selected, a recording of the beam intensity is made on a high resolution negative photographic plate. The plate is developed in a unity gamma process and is then reinserted in the beam in precise registration to produce a beam of uniform intensity. The appearance of a typical mask is shown in Fig. 4-12. (The mask used is a negative of that shown in the photograph.)

The schematic of Fig. 4-9 and the photographs of Figs. 4-10 and 4-11 show the recording system as it currently exists in our laboratories with spherical correction lenses and intensity mask in place. This system, constructed primarily on internal RCA programs, will be maintained for some months for further experiments and recording. The system is capable of recording focused image holograms as well as quasi-focused image information and would be used for any program requiring up to 100 holograms in the formats similar to the moving map hologram. This system would be modified to increase its stability and to produce semiautomated operation if high numbers of holograms were required.
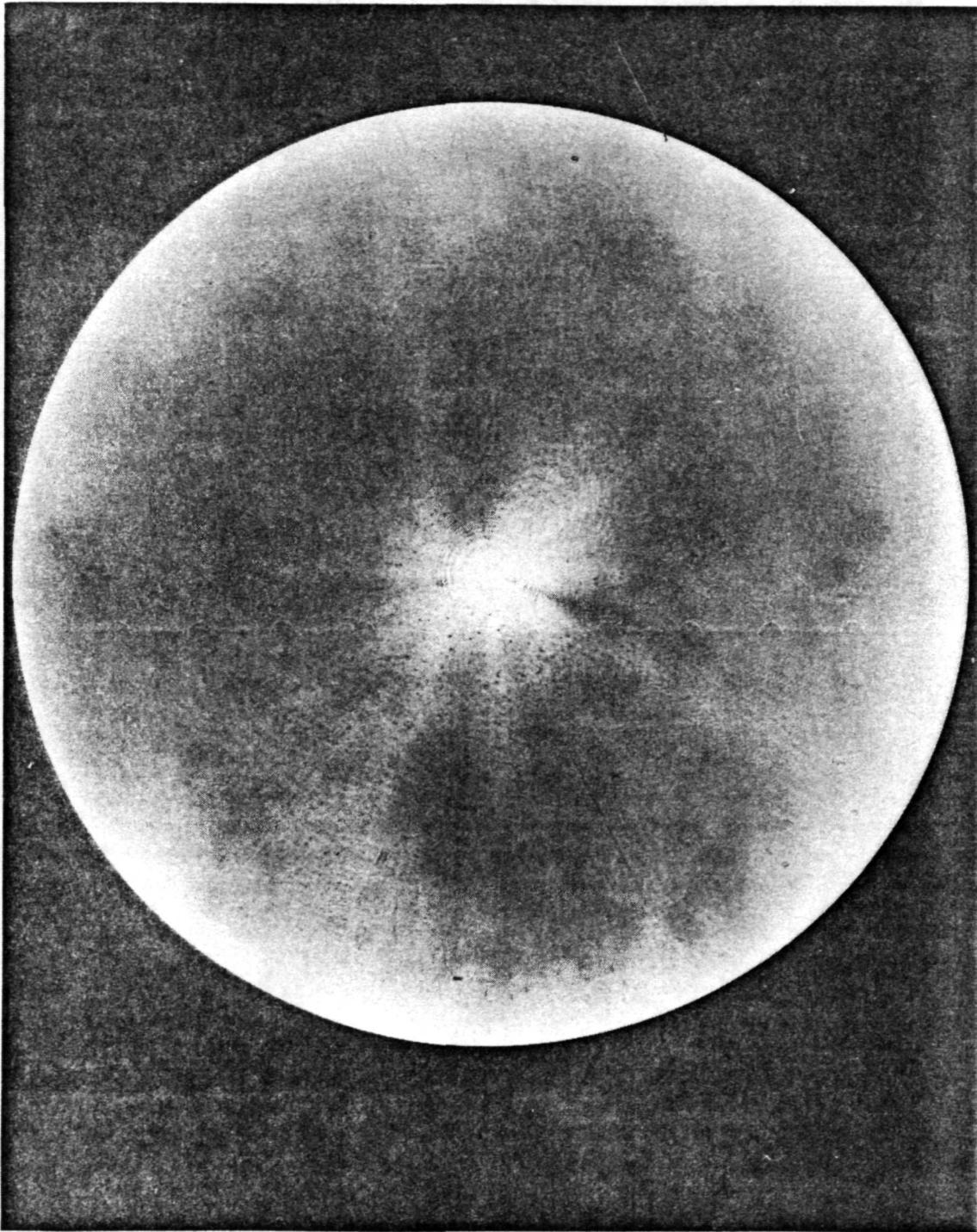
Fig. 4-12. Correction master.

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## C. INDEXING AND REGISTRATION INFORMATION

### 1. Indexing

Indexing information is recorded using a Fraunhofer hologram embossed on the back side of the vinyl storage tape used to record the map information.

The Fraunhofer hologram is used to record the indexing information; it is recorded in a system having the configuration indicated in Fig. 4-13 and pictured in Fig. 4-14. In this setup the output from a HeCd laser is split into a reference beam and an object beam. The object beam is focused to a pinhole by a 20-power microscope objective and then allowed to expand to fill a four-inch diameter lens placed at a distance equal to its focal length away from the pinhole; this lens thus provides a collimated beam. The collimated beam is dissected into 8 segments by a 4- by 2-element mirror array (system can be extended to 10 segments for a 500-frame system). The mirror array directs each of the dissected bundles to a common recording area on a holographic plate which is masked to allow recording over a 4-mm by 4-mm area.

The reference beam used to form the interference pattern (the hologram) is shaped to a plane wavefront and made to interfere at the photoresist–coated holographic plate with the composite beam derived from the mirror array. A dodging mask is
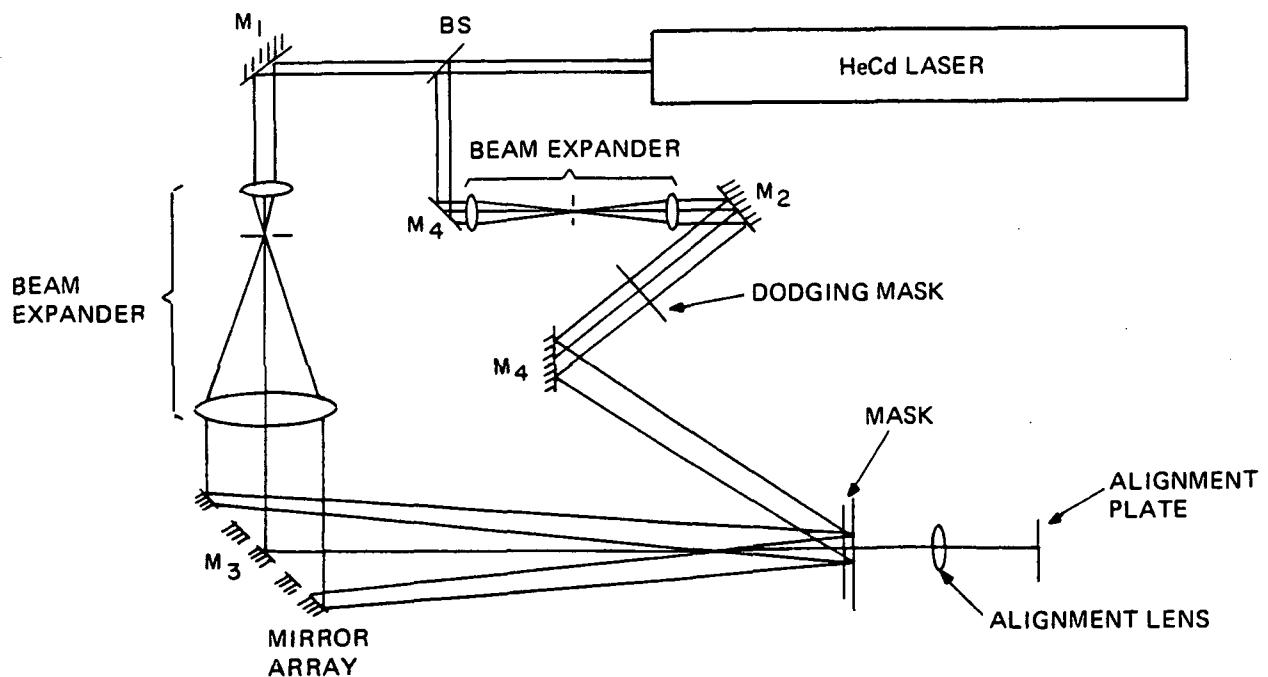


Fig. 4-13. Index hologram recording schematic.

Fig. 4-14. Index recording system hardware.

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included in the reference beam to prevent the generation of sharp edges - which interfere with the image information - when recording the indexing hologram.

A registration plate is included in the laboratory setup to ensure that the mirrors are correctly aligned as shown in Fig. 4-13. Coded information is introduced by masking the mirrors so that no energy is reflected from a mirror which is inserted in a zero bit path.

The recorded hologram has the properties of a Fraunhofer hologram; linear motion of the hologram in a plane perpendicular to the reconstruction optical system produces no image motion. Consequently, if a 2- by 4-element detector were properly registered in the image plane it would sense the presence of the recorded bits as long as the reference beam passes through the active area of the hologram.

If the detection system were designed to accommodate a 500-hologram system, 9 bits must be used to record indexing (or frame designation) information while one remaining bit is used for synchronization. The synchronization bit is used to prevent spurious readings from adversely affecting the operation of the retrieval transport control system as the film is moved from one hologram to the next.

An important consideration related to the design of this system is illustrated in Fig. 4-15. The recording process is performed using the 4416 Å line of the HeCd laser. The coherence of a gas laser is required for recording because, as is typical of holographic recording systems, a coherent source must be employed to develop the interference pattern between the two wavefronts. The 4416 Å line was selected because it closely matches the peak spectral response line of the photoresist employed.

However, it is not desirable to introduce a gas laser source into the display unit. A quick analysis shows that, for the resolution required, a GaAs laser source will posses sufficient coherence to restore the ten-bit indexing information. The use of a GaAs diode with a collimating lens requires that a compensation be made when recording to accommodate the shift in wavelength from the 4416 Å source used to record and the 9050 Å room-temperature radiation of the GaAs diode used for reconstruction.



SENSOR
PLANE

FROM
READOUT
SOURCE
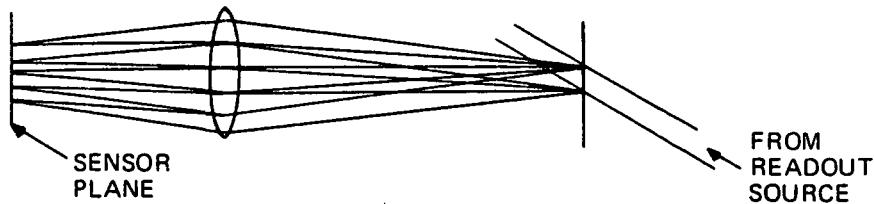
Fig. 4-15. Index hologram reconstruction.

It is to be remembered that the holographic restoration process is a diffraction process and obeys the diffraction equation:

$$\theta = \sin^{-1} \frac{\lambda}{\delta}$$

$\theta$ = restoration beam angle

$\lambda$ = wavelength of source

$\delta$ = grating pitch

Assuming a grating of given pitch, and further assuming (as is the case in the implemented display model) that a reconstruction angle, $\theta_R$, of 47° is required, the recording angle must be

$$\theta_R = \sin^{-1} \left[ \frac{\lambda_R}{\lambda_B} \sin \theta_B \right]$$

or

$$\theta_R = 21°$$

$\theta_R$ = red reconstruction angle

$\theta_B$ = blue recording angle

$\lambda_R$ = wavelength, red, 905.0 $\mu$m

$\lambda_B$ = wavelength, blue, 441.6 $\mu$m

## D. HOLOGRAM DUPLICATION

One of the major reasons for employing a holographic storage technique for use in the multifunction display is that this storage technique allows rapid field duplication of the recorded information on an inexpensive storage medium.

The ability to rapidly and inexpensively duplicate holograms leads to a system utilization concept in which the holograms containing the image information are produced as relief image holograms on photoresist. These holograms are used to form first generation metallic masters. The metallic masters are then used to form second generation metallic embossing masters which are distributed to the location where the image information is to be stored. The image data is received at these stations as metallic holographic map chips or tapes. The holographic masters are used locally to transfer the image information to a 16-mm storage tape strip, which in a field application would be composed of a vinyl or acetate material.

A detailed discussion of the embossing process follows. The holograms are formed as surface relief images on photoresist. The photoresist (a modified version of Shipley AZ-1350) is deposited on a substrate to a depth of several micrometers. The relief image is developed to a depth of 0.2 to 0.4 nanometer. A glass substrate was used to support the photoresist used for the generation of original holograms for the multifunction display. Holograms have also been made with the photoresist deposited on mylar and cronar bases. A cronar base will be used almost exclusively on later programs where it is desired to record large numbers of holograms. This will allow the recording of holograms on strips which can in turn be run through the development and plating process in batches.

As the next step in the duplication process, the surface relief hologram is gold plated in either a chemical or vacuum deposition process to a thickness of several microns (both processes have been used successfully). At the present time a standard gold vacuum deposition technique is employed. The chemical process also produces satisfactory results, using either gold or silver, but requires the mixing of chemicals with relatively short shelf lives and in addition requires that more care be taken in maintaining a clean environment when mixing photoresist and depositing it on the substrate material.

Consequently, since both methods produce comparable results, the vacuum deposition technique is more conveniently employed as long as the number of holograms remains small. If a large number of holograms were to be produced, the chemical deposition process would be employed.

The gold-plated slide is used as the cathode in a plating process in which nickel is deposited on the silvered surface to a depth of several mils. The process used is a standard nickel plating process.

The metallic plating, which is easily freed from the photoresist master, has on the interface surface a negative impression of the original hologram. (The negative impression is not a negative in the sense of a photographic negative. For in a holographic recording it is the presence or absence of a grating which produces the diffraction effect. An interchange of the lands and valleys which make-up the grating produces no change in the restored wavefront.) This grating could be read out directly as a reflection hologram. In the present program this metallic copy is used as an embossing master to ransfer the hologram to the vinyl storage material used in the display. The silver-nickel surface is very hard and can be used to produce tens of thousands of copies of the original hologram with little if any degradation. (If silver is used for masters which are to be stored for long times it is desirable to eliminate the silver and replace it with a chrome plating to prevent degradation of the master due to tarnishing of the silver.) Resolutions can be held through the entire process in excess of 1500 lp/mm.

A second generation of masters can be produced from the original metallic master. In this process the gold or silver surface is neutralized by a proprietary process and the neutralized nickel master is again nickel plated. As in the original case the nickel is allowed to build up to a thickness of several mils before the plated master is removed from the electrolytic tank. The newly deposited nickel can be stripped from the treated master and chrome plated. As in the case of the original hologram, there is little or no degradation introduced by this process. In addition, the process can be repeated almost an unlimited number of times with no degradation of the original metallic master.

Second-generation masters can also be produced from the vinyl copies using the same plating process used to form the first generation masters from the original photoresist hologram.

The process used to transfer the hologram from the metallic master to the storage material used in the display is an embossing process similar to that used to stamp phonograph records. The technique currently implemented in our laboratory employs the stamping mechanism of Fig. 4-16. This device is capable of simultaneously embossing holograms on both sides of the film strip.

In the present embossing system a focused image multicolor hologram is precisely positioned on a shoe mechanism and clamped in place. The shoe is placed on the anvil of Fig. 4-16. The shoe is designed so that it is self-seating and self-registering. A second hologram containing the Fraunhofer indexing and Fresnel registration information is mounted on a shoe which is also inserted on the anvil so that the two holograms overlap and face each other and are located below the mandrel shown in the figure. The tape to be embossed is sandwiched between the two nickel masters. The holographic areas on the mandrel and anvil are thermally isolated from the rest of the structure. These elements are rapidly heated by passing current through a nickel foil positioned as shown in Fig 4-17. The amount of current passed through the foil is dependent on the desired embossing temperature which (for the case of vinyl) is approximately 100°C. This heating operation requires about 8 seconds (current/time tradeoffs can be made). As the mandrel is heated it is pressed into the storage medium by applying a calibrated force to the lever arm, A. The heat is transferred to the film, causing the material to soften so that it assumes the shape of the two holographic masters positioned on either side of the storage film. The heater is turned off and the vinyl is allowed to cool. A cooling line of 8 to 10 seconds is required, after which time the pressure is released and the film freed. The system is then set up to emboss the next set of holograms.

The embossing system described above was used to produce the holograms delivered with the Multifunction Display System. This custom system is designed to handle a limited number of holograms. The system described would be modified if it were required to emboss a large number of holograms or if the embossing were to be performed in the field.

Fig. 4-16. Embossing mechanism.
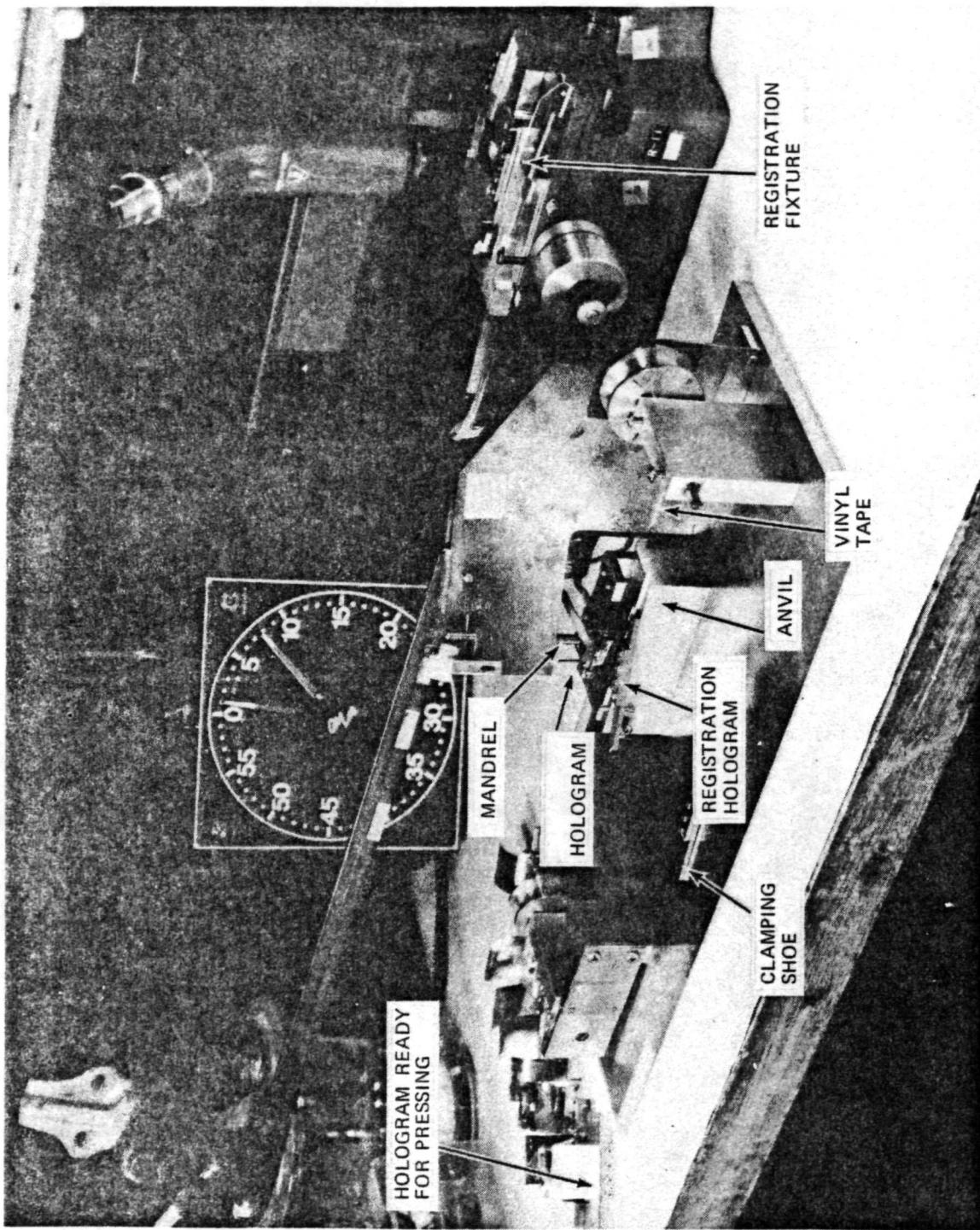
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EMBOSSING ANVIL

INDEX SHOE (REGISTRATION HOLOGRAM)

NICKEL HEATING FOIL

REGISTRATION SHOE (INDEX HOLOGRAM)
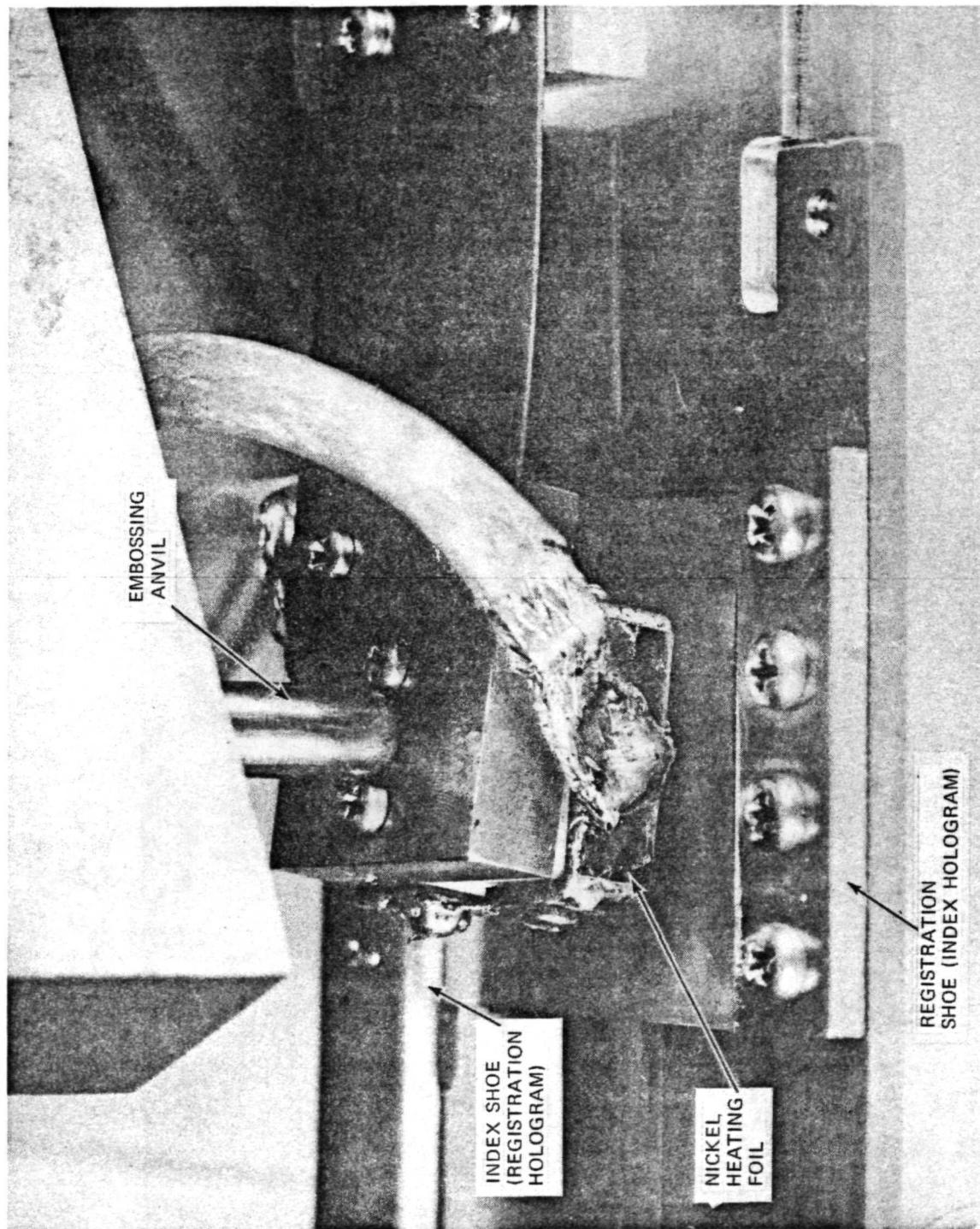
Fig. 4-17. Embossing head.

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4-28

Current concepts of system utilization envision the use of hologram masters in the form of metallic tape strips to emboss large numbers of holograms. With this technique holograms can be reproduced by a high speed process in which the copies are formed using heated pinch rollers as shown in the conceptual diagram of Fig. 4-18. In this concept, the image information is recorded on the upper side of the storage tape while the frame indexing and registering information is embossed on the lower side of the tape by holograms recorded on an indexing tape. Techniques must be developed to precisely register these tapes for high speed duplication.

RCA has demonstrated the capability of embossing between heated pinch rollers at speeds in excess of 60 ips. Embossing at this speed, a 500-hologram tape could be duplicated from a master in under 5 seconds. This time is somewhat optimistic, particularly if the holograms are batched in 30-hologram tape strips. But in any case it is not unreasonable to consider duplication times of the order of minutes for a 500-frame hologram tape.

## E. EXPOSURE CONTROL

The precise registration required to produce restored images of high quality has required that the method of recording the holograms be modified. In the original process a color separation was introduced in the object plane of Fig. 4-9 and an exposure was made. The second element of the color separation set was then introduced into the object plane but with its north axis oriented at 45 degrees to the original separation and with the holographic recording plate rotated by the same amount.
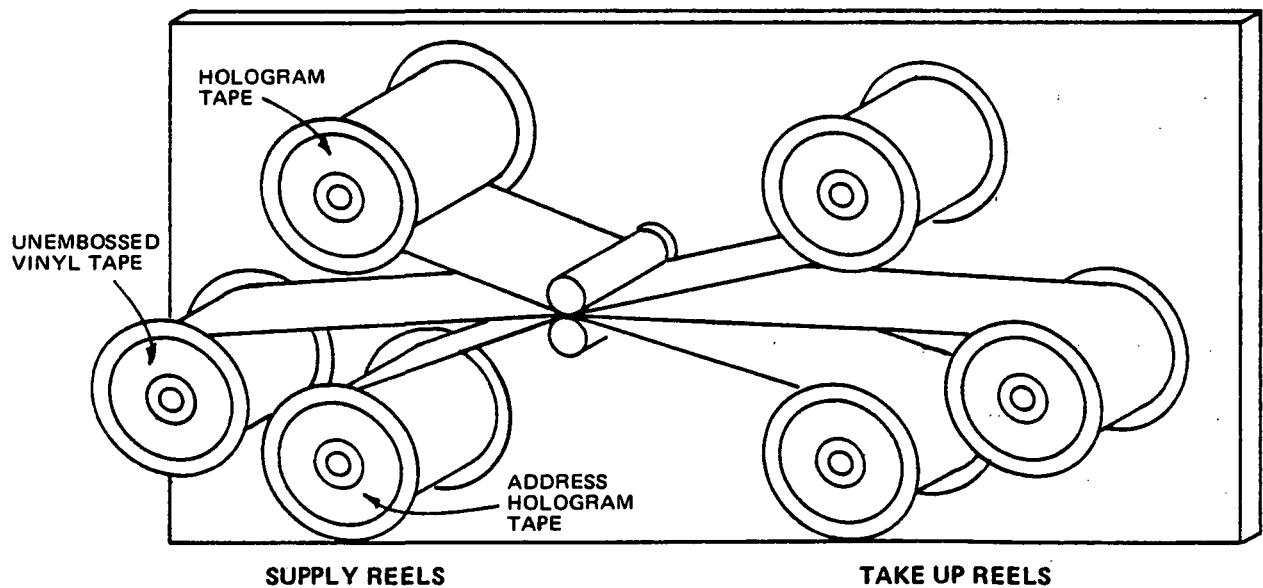


Fig. 4-18. High speed embossing concept.

A third hologram was next made in the same area using as an object the third color separation with its north axis rotated 90 degrees from the original position and with the holographic plate rotated by a corresponding amount. The exposed holographic plate was then removed from the plate holder and developed. If two side-by-side holograms were to be produced, six exposures were made before developing the plate.

This system was found to be very difficult to implement in a fashion which would provide accurately registered exposures, particularly in light of difficulty encountered in the placement of the registration holes on the color separations for use in a pin registration system. Consequently, a system was used in which a hologram of the blue color separation was first recorded on a photoresist material and developed. The exposures were made using a helium cadmium laser. The reference beam and object beam were balanced; highlight energy levels of approximately 1 to 2 millijoules were used for exposure. The exposure time was approximately 3 seconds using a 10 mW laser. The holographic plate was then removed from the plate holder and lightly developed. (Placed in the developing solution for about one second.) If side-by-side holograms are to be recorded, blue separations are exposed side-by-side prior to this development. The registration accuracy of the pinning system is sufficiently accurate to allow the registration of two holograms side by side but is not sufficiently accurate to allow the registration of successive frames of a given color separation set.

After lightly developing the blue separation hologram(s) the holographic plate was reinserted in the plate holder and rotated 45° to the proper angle to record the red color separation. The blue hologram was read out using a microscope by an off-axis filtered source, preventing exposure of the photoresist by this registration source. The red color separation was then placed in the object plane and projected to the holographic recording plane by a second light source. The recorded blue hologram was then moved until the two images (the red projected image and the blue holographic) were registered. A hologram of the red color separation was then formed using the HeCd laser. The exposure in this instance was about ten to twenty percent higher than that used to produce the blue hologram.

The red separation was then removed from the object plane and the green separation inserted. The holographic plate was rotated 90 degrees from the position of the blue separation recording. The blue hologram was again illuminated with a red light source and observed through the microscope. (This requires a light source placed at a different location than that used during the red hologram exposure process.) A projected image of the green color separation was then projected to the same image plane and the holographic plate moved to register the blue holographically-projected image and the green image. Once registered a third exposure was made. The exposure level for this exposure is about the same as that used to form the red recording.

After the recording operation is complete, the holographic plate is developed for a period of about 3 to 5 seconds. The plate is then removed from the developer, washed in water, dried, and checked for exposure balance and overall quality. If the plate is satisfactory, it is ready for the plating and embossing process.

# Section V

# CONCLUSIONS

(1) The combination of a high density holographic storage and retrieval system and a transparent plasma panel offer an effective method of presenting real-time computer generated information and archival information for superimposed simultaneous viewing.

(2) The delivered system has an 8-1/2-inch x 8-1/2-inch viewing aperture. Volatile information is presented in this aperture with a resolution of 60 elements per inch, while archival multicolor information is displayed at 250 elements per inch. Recent advances in plasma panel technology and in techniques for increasing the brightness and storage capability of the holographic system offer the potential for doubling the display size while maintaining the unit resolution the same as in the delivered display.

(3) A limited set of holograms was delivered with the system. The system capability can only be truly demonstrated by extending the number of stored frames.

(4) The brightness of the holographically projected information in the current display can be increased by modification of the optical source. This modification which requires the use of multiple optical sources will increase the display brightness by a factor of three.

(5) The holographically displayed information's contrast may be increased by modifying the internal structure of the plasma panel. The modification consists of the development of an electrode structure which has a lamp black appearance rather than a reflective gold appearance as is the case in the present panel produced by Owens-Illinois. Owens-Illinois has postulated, but not implemented such an electrode structure.

(6) The delivered system employs technologies which range from those which are well within the state-of-the-art to those which are on the forefront of an evolving technology. The local control and interface system employs commercial hardware. (Data General's Nova Systems). This hardware has been modified to the extent necessary to drive the plasma panel control electronics and the holographic retrieval system. The plasma panel is in production by Owens-Illinois. Recent advances show the promise of larger panels with better optical characteristics. The multicolor holographic storage technology is a technology that is undergoing rapid advances. This work is being supported by the Navy, the Air Force and internally by RCA in addition to the support supplied by NASA.

(7)  Holography was selected as the archival storage technique because it offers a number of advantages not found in more conventional techniques.  These advantages include the following, as compared to conventional color microfilm:

    (a)  A higher information storage density for equivalent signal to noise ratios.

    (b)  A storage medium which, even when subjected to high readout optical power densities does not fade, nor does it absorb energy from the optical source.

    (c)  A technique which allows multiple holograms to be stored in a common storage area.

    (d)  Frame address information is recorded using a redundant technique which has a high tolerance to misalignment as well as to scratches and abrasions.

    (e)  An inexpensive storage medium.

    (f)  A low cost rapid duplication process.

(8)  There are no inherent limitations in the technologies employed in the assembled system that would preclude the development of later systems for use in a spacecraft environment.

(9)  The delivered equipment was assembled using commercial practices.  No attempt was made to minimize the display size or power requirement.  Significant reductions could be achieved in these areas.

(10)  RCA will maintain (at least until the end of 1974) and is improving a holographic recording system which can be modified to record holograms in the NASA configuration.

(11)  A precise automatic registration system is currently under development for the Navy which could be implemented in the NASA system.

(12)  RCA firmly believes that the multicolor storage system of the type implemented in the NASA Multifunction Display will be used in wide variety of applications where it is desired to dynamically annotate multicolor archival information.

(13)  The holographic storage technique employed in the Multifunction Display, although requiring a laser for construction of the storage hologram, may be read out using a white light source.